ACTIVITY AND EMISSIONS ASSOCIATED WITH HIGHWAY CONSTRUCTION PROJECTS: CASE STUDIES IN DALLAS/FORT WORTH, TEXAS

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by

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16. Abstract

Highway and road construction is necessary to both improve deteriorating or under-capacity roads and to provide new linkages between points of demand. Recent public concerns, prompted by regional ozone alert programs, created the need for assessing the contribution of emissions from highway construction projects to a region's air quality.

An assessment of highway construction project emissions was performed at five study sites in Dallas/Fort Worth, Texas. Four large scale, multi-year construction projects and one small pavement maintenance project were observed.

Several types of information were collected from field trucks, materials trucks, and construction equipment. Vehicles were classified according to MOBILE definitions, and the remaining equipment was classified according to AP-42 definitions. Engine starts and stops were recorded from field trucks, as well as the fuel type used and the initial odometer reading. Materials trucks and construction equipment were observed and their activities recorded. The activity measures recorded were engine starts, operating hours, and the frequency and duration of throttles (transient events).

Activity from field trucks, materials trucks, and construction equipment was used to estimate the emissions produced at each study site. These emissions estimates were then placed in perspective by comparing their equivalent vehicle miles of travel (VMT) for the general vehicle fleet in the region. An additional comparison was made by expanding the highway construction activity and resulting emissions over the two-county region and comparing this to the emissions generated from on-road mobile sources.

The results show that highway construction emissions contribute to less than 1% of the on-road mobile source carbon monoxide and hydrocarbon emissions inventories, and less than 3% to the on-road mobile source nitrogen oxides emissions inventory. Therefore, these results show that highway construction emissions are insignificant to a region's total emissions inventory.

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IMPLEMENTATION STATEMENT

The results of research documented in this report answer immediate questions raised by the staff at the division and district levels at the Texas Department of Transportation (TxDOT). Specifically, these questions concern the impact of highway construction activities on air quality.

With the adoption of "Ozone Action," or alert days that promote restricting activities or modifying behaviors that contribute to the formation of ozone precursors (hydrocarbons and nitrogen oxides), highway construction activities have come under criticism from the public. This research sought to quantify the contribution of highway construction projects to regional air emissions inventories. The findings show that contributions to regional emissions inventories from highway construction projects are insignificant.

From these results, additional information is now available for developing departmental policies that address these concerns. The report also contains information that may be useful to district or division personnel who are working on local air quality issues and addressing concerns expressed by citizens who view TxDOT's construction activities as detrimental to a region's air quality.

This report has not been converted to metric units because the software used to develop the emissions rates relies on input to and output from the Environmental Protection Agency's MOBILE emission factor model. As of the publication of this report, English inputs are required for MOBILE, and inclusion of metric equivalents could cause some user input error.

DISCLAIMER

The contents of this report reflect the views of the author who is responsible for the facts and the accuracy of the data presented hererin. The contents do not necessarily reflect the official view or policies of the Federal Highway Administration (FHWA) or TxDOT. This report does not constitute a standard, specification, or regulation. It is not intended for construction, bidding, or permit purposes. Jason A. Crawford, Assistant Research Engineer, prepared the report. Dr. George B. Dresser was the Research Supervisor.

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Dallas District:

Mr. Jim Hunt P.E., Director of Construction

Mr. Tony Peyberah P.E., Associate Area Engineer, Northeast Dallas Area (North Central Expressway S-2 Contract)

Mr. Wallace Heimer, formerly of TxDOT in the Northeast Dallas Area (North Central Expressway S-1 Contract)

Fort Worth District:

Mr. Harvey Opperman, South Tarrant County Area Engineer, (I-35W/I-30 Interchange)

Mr. Kirk Lee, Engineering Specialist (I-35W/I-30 Interchange)

Mr. Doug Keesey, Engineering Specialist III, North Tarrant County Area Office (I-820 NE Interchange)

Mr. John Ward, Engineering Technician III (FM 156 Maintenance)

Mr. Jerry Cutter, Engineering Specialist III, (FM 156 Maintenance)

Mr. Robert Julian, Director of District Construction

The team also extends its appreciation to the data collection staff in the Texas Transpotation Institute's (TTI) Arlington Regional Office who performed their duties above expectations given the challenges they faced in this project. These individuals include Mr. Stephen Ranft, Ms. Diana Wallace, Mr. Joseph Slack, Mr. Jimm Blagrave, and Mr. Harry Marshall.

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SUMMARY

Highway and road construction is necessary to both improve deteriorating or under capacity roads and to provide new linkages between points of demand. Recent public concern, prompted by regional ozone alert programs, created the need for assessing the contribution of emissions from highway construction projects to a region's air quality.

TTI conducted an assessment of highway construction project emissions at five study sites in Dallas/Fort Worth (D/FW), Texas. The research team observed four large scale, multi-year construction projects and one small pavement maintenance project.

The research team collected several types of information from field trucks, materials trucks, and construction equipment. Vehicles were classified according to MOBILE definitions, and the remaining equipment was classified according to AP-42 definitions. Engine starts and stops were recorded from field trucks, as well as the fuel type used and the initial odometer reading. The team observed materials trucks and construction equipment and recorded their activities. The activity measures recorded were engine starts, operating hours, and the frequency and duration of throttles (transient events).

Activity from field trucks, materials trucks, and construction equipment were used to estimate the emissions produced at each study site. These emissions estimates were then placed in perspective by comparing their equivalent VMT for the general vehicle fleet in the region. The team made an additional comparison by expanding the highway construction activity and resulting emissions over the two-county region and comparing this to the emissions generated from on-road mobile sources.

The results show that highway construction emissions contribute to less than 1% of the on-road mobile source carbon monoxide (CO) and hydrocarbon (HC) emissions inventories, and less than 3% to the on-road mobile source nitrogen oxides (NOx) emissions inventory. From these results, the research team determined that highway construction emissions are insignificant to a region's total emissions inventory.

CHAPTER I. INTRODUCTION

Highway and road construction is necessary to both improve deteriorating or under capacity roads, and to provide new linkages between points of demand. New or expanded capacity helps relieve traffic congestion, thus improving mobility in the region. Roadway maintenance is important to ensure the safety of the traveling public and to maintain transportation investments.

Construction activity results in three distinct impacts: (1) dust, (2) traffic congestion due to construction, and (3) emissions from construction equipment (1). Dust is produced on a construction site by ground excavation, earth-moving operations, wind erosion, and from equipment and vehicles traveling along unpaved roads. Dust emissions can vary day to day, depending on the level of construction activity, and weather conditions (2). Traffic congestion caused by construction is considered temporary in nature and therefore insignificant to regional assessments of air quality. Emissions generated from construction equipment are also considered temporary in nature and insignificant to regional air quality assessments.

Typically, construction equipment is considered to have a temporary contribution to regional air quality levels (1); however, the research team did not find previous studies supporting this assumption. With the implementation of "Ozone Alert/Action Days," construction activity has come under closer public scrutiny. Motorists and the public are encouraged to modify their travel behavior, reduce or postpone the use of small equipment, and to postpone vehicle/equipment refueling. Because government encourages the public to change its behavior, other activities that use gasoline- or diesel-powered engines have come under scrutiny.

To address these public concerns, a need exists to assess contributions to regional air quality from highway construction projects. Some regions have implemented measures to reduce certain activities or the use of materials. However, there are no controls on the use of heavy construction equipment. Before considering stricter controls at construction sites, there is a need to assess the emissions contributions at these sites.

OFF-ROAD ENGINE REGULATIONS

In fall 1997, the Environmental Protection Agency (EPA) announced a program (3) to cut emissions from diesel engines. This represents the EPA's initial effort to regulate emissions from nonroad diesel engines. EPA proposed phasing-in tighter emissions limits for nonroad diesel engines. They estimated that the proposal would reduce pollution by 2.7 million tons per year. This reduction is equivalent to taking six million heavy trucks off the road. The improved engines would be phased in starting in 1999 and continuing through the year 2008. Once implemented, the EPA estimates the improved engines will reduce up to 2/3 of the NOx and particulate matter (PM) currently produced. The resulting emissions reduction would cost approximately $300 or less per ton of NOx reduced and would add about 2% or less to the purchase price of each engine.

EMISSIONS RATES FOR CONSTRUCTION EQUIPMENT

Currently, the EPA's AP-42 document contains reported emissions rates for construction equipment. This document provides guidance on assessing emissions from a variety of stationary, area, and mobile sources. The document includes emissions rates for many non automobile engines such as rail locomotives, aircraft engines, and construction equipment.

The emissions factors in AP-42 for heavy-duty diesel construction equipment are based on a 1984 study by Environmental Research and Technology Inc. (4). Equipment is divided into 10 categories and divided further by fuel type (diesel or gasoline) as shown in Table 1-1.

TABLE 1-1
AP-42 HEAVY-DUTY CONSTRUCTION EQUIPMENT CATEGORIES

Equipment Category	Diesel	Gasoline
Track-type Tractors	X	
Track-type Loaders	X	
Motor Graders	X	X
Scraper	X	
Wheeled Dozer	X	
Off-highway Trucks (includes pavement cold planers and wheel dozers)	X	
Wheeled Loaders	X	X
Wheeled Tractors	X	X
Rollers (static and vibratory)	X	X
Miscellaneous	X	X

Equipment typified in the Miscellaneous category includes less numerous mobile and semi-mobile equipment such as log skidders, hydraulic excavators/crawlers, trenchers, concrete pavers, compact loaders, crane lattice booms, cranes, hydraulic excavator wheels, and bituminous pavers. The category also includes small portable equipment such as generators. The approximate annual operating hours of the heavy construction vehicle types are shown in Table 1-2.

TABLE 1-2
ANNUAL OPERATING HOURS OF CONSTRUCTION EQUIPMENT

Category	Annual Operation (hours/year)
Track-laying Tractors	1,050
Track-laying Shovel Loaders	1,100
Motor Graders	830
Scrapers	2,000
Off-highway Trucks	4,000
Off-highway Trucks and Wheeled Dozers	2,000
Wheeled Loaders	1,140
Wheeled Tractors	740
Rollers	740
Miscellaneous	1,000

Source: (4)

Construction equipment emissions are calculated using either of two methods. The methods are the time-based and the "brake specific" approaches.

The time-based approach requires the use of estimated annual equipment usage in hours or daily equipment usage in hours. AP-42 provides guidance for annual equipment usage; hour meters on equipment in the field are used to collect daily equipment usage. Emissions rates are then applied to the total hourly usage for each of AP-42 construction equipment categories, as shown in the following equation:

$$E = EF * H$$

where,

E = time-based emissions

EF = emissions factor

H = hours of use

The "brake specific" approach is the most accurate method for calculating emissions. This method requires calculating emissions using an equipment usage, rated power, and load factor. The equation below shows this relationship:

$$E = EF_{bs} * H * P * L_f$$

where,

- E = brake specific emissions
- EF_{bs} = brake specific emissions factor
- H = hours of use
- P = rated power (Hp)
- L_f = load factor (ratio of actual power used to power available).

CURRENT AND ANTICIPATED RESEARCH

The EPA is developing tools to help practitioners assess the impacts of nonroad mobile sources. EPA is currently developing a nonroad mobile source emissions model called the NONROAD model. Release of a beta version is expected during the summer of 1998. This model is being developed "because of the significant contribution of nonroad emissions sources to the total mobile source emissions inventory (5)." The EPA reported in 1991 that nonroad vehicles and equipment were a significant source of volitale organic compounds (VOC), CO, and NOx emissions (6). In some areas of the nation, nonroad emissions contributed to as much as one-third of the total mobile source NOx and VOC inventory (5).

The NONROAD model is capable of estimating emissions for the following types of vehicles and equipment:

- airport ground support;
- agricultural equipment;
- construction equipment;
- industrial and commercial equipment;
- recreational vehicles;
- residential and commercial lawn and garden equipment;
- logging equipment;

- recreational marine equipment;
- underground mining equipment; and
- oil field equipment.

Emissions from aircraft, locomotives, or commercial marine equipment may be added to the model prior to its final release.

The model covers more than 80 basic and 260 specific types of nonroad equipment. The model also stratifies the equipment by horsepower ratings. Additionally, four fuel types are included: gasoline, diesel, compressed natural gas (CNG), and liquified petroleum gas (LPG). The model will also distinguish between 2- and 4-stroke gasoline and diesel engines.

The model will estimate emissions for six pollutants: HC, NOx, CO, carbon dioxide (CO_2), sulphur oxides (SOx), and PM. The model can report HC emissions as total hydrocarbons (THC), total organic compounds (TOG), non-methane organic compounds (NMOG), non-methane hydrocarbons (NMHC), and VOC. PM is reported as total amount less than 10 μ (PM10) or total amount less than 2.5 μ (PM2.5). Non-exhaust HC emissions are provided for six modes: hot soak, diurnal, refueling, resting loss, running loss, and crankcase emissions. These emissions are estimated for equipment operation in both steady state and transient conditions.

The emissions are estimated on a national level and are functions of engine equipment population, annual hours of use, horsepower, engine load factor, and average emissions (6). The model will also account for the benefits of Tier 1 nonroad standards.

EMISSIONS ASSOCIATED WITH PAINTING

The application of painted highway markings and painting exterior structure surfaces and signs are all applications of surface coatings. VOC emissions originate from paint vehicles, thinners, or solvents. Almost all emissions from surface coatings occur during application. Emissions factors for various types of surface coating applications are shown in Table 1-3.

TABLE 1-3
EMISSIONS FACTORS OF SURFACE COATING APPLICATIONS

Coating Type	Emissions kg/Mg	Emissions lb/ton
Paint	560	1,120
Varnish and Shellac	500	1,000
Lacquer	770	1,540
Enamel	420	840
Primer (zinc chromate)	660	1,320

Source: (2)

EMISSIONS ASSOCIATED WITH ASPHALT APPLICATION

Emissions from asphalt application are almost exclusively from VOC. Asphalt types are emulsified asphalt, asphalt cement, and cutback asphalt. The only significant emissions originate from cutback asphalt, which is composed of asphalt cement and diluents. Diluents vary from 25% to 45% by volume. TxDOT used 27,947,608 liters (7,383,000 gallons) of cutback asphalt at highway construction projects, statewide, in 1997 (7). This asphalt usage reflects TxDOT restrictions and those imposed by the Texas Natural Resource Conservation Commission (TNRCC). The TNRCC restrictions apply to a greater number of Texas cities and thus highway construction projects, whereas the TxDOT restrictions were localized to the City of San Antonio.

San Antonio was the only city in Texas where TxDOT imposed restrictions on the use of MC and RC asphalts ". . .for surface treatment, prime or tack coats, etc. . ." during the ozone season for state highway construction contracts. TxDOT also restricted the use of HMCL (hot-mixed, cold-laid) and/or limestone rock aggregate (LRA) until after 12:00 noon on ozone action days. These contractual provisions applied to and inside of IH-410 (San Antonio's loop). These and other actions affecting highway construction projects were taken to contribute to the San Antonio region's efforts of improving or maintaining its air quality to avoid becoming designated as an ozone nonattainment area. These contractual restrictions were lifted in late 1997 as a result of stricter ozone guidelines adopted by the Environmental Protection Agency (13).

The TNRCC currently restricts the "use, application, sale or offering for sale of cutback asphalts containing VOC solvents" during the ozone season, defined in their rules from April 16 to September 15 of any year in each of the four Texas nonattainment areas and Nueces County (14). Maximum VOC content limitations are also placed on the use of emulsified asphalt when this material is used to comply with the cutback asphalt restriction. Exemptions from the cutback asphalt restriction are cutback asphalts (1) used for patching which is stored in a long-life stockpile and (2) the use of cutback asphalts solely as a penetrating prime coat (14).

There are three types of cutback asphalt: rapid cure (RC), medium cure (MC), and slow cure (SC). Cure depends on the type of diluent used. SC cutback asphalt contains heavy residual oils, MC cutback asphalt contains kerosene-type solvents, and RC cutback asphalt contains gasoline-type solvents. Accrued evaporation of diluent, from time of application, occurs as shown in Table 1-4.

TABLE 1-4
ACCRUED EVAPORATION OF CUTBACK ASPHALT DILUENTS

Cutback Asphalt Type	**Time after Application**		
	Next Day	**Next Month**	**Four Months**
Rapid Cure (RC)	75 %	90 %	95 %
Medium Cure (MC)	20 %	50 %	70 %
Slow Cure (SC)	No data, but greatly less		~ 25 %

Source: (4)

To calculate emissions associated with asphalt application when the mass of cutback asphalt is known, use the following steps. First, solve the volume of diluent with the following simultaneous equations:

Total Mass of Cutback = (Volume of Diluent)(Density of Diluent) + (Volume of Asphalt Cement) (Density of Asphalt Cement)

and

Volume of Diluent = (Percent Diluent) (Volume of Diluent + Volume of Asphalt Cement)

The density of asphalt cement is 1.1 kg/l. The densities of diluent for the cutback asphalt types are 0.9 kg/l for SC, 0.8 kg/l for MC, and 0.7 kg/l for RC. Second, solve the mass of the diluent. Calculate the mass of the diluent using the following equation:

$$\textit{Mass of Diluent} = (\textit{Volume of Diluent})\ (\textit{Density of Diluent})$$

Finally, calculate the emissions using the following equation:

$$\textit{Emissions} = (\%\ \textit{Accrued Evaporation})\ (\textit{Mass of Diluent})$$

EMISSIONS INVENTORIES

Emissions inventories are required for both ozone and CO nonattainment areas. As part of the State Implementation Plan (SIP), these inventories estimate total emissions by source category, such as biogenic sources and anthropogenic, stationary, area, and mobile sources. The emissions inventories provide a basis for measuring air quality and demonstrating any reduction achieved through air quality improvement programs.

Emissions inventories for metropolitan areas do not typically include emissions produced from activities at construction sites. As stated previously, construction sites are not included because they are considered insignificant to the overall metropolitan area.

Figure 1-1 shows the contributions to the 1990 Dallas/Fort Worth (D/FW) nonattainment area VOC emissions inventory. Off-road mobile sources, which include construction equipment, accounted for 18% of the total VOC emissions, which is slightly less than half of the on-road mobile source emissions.

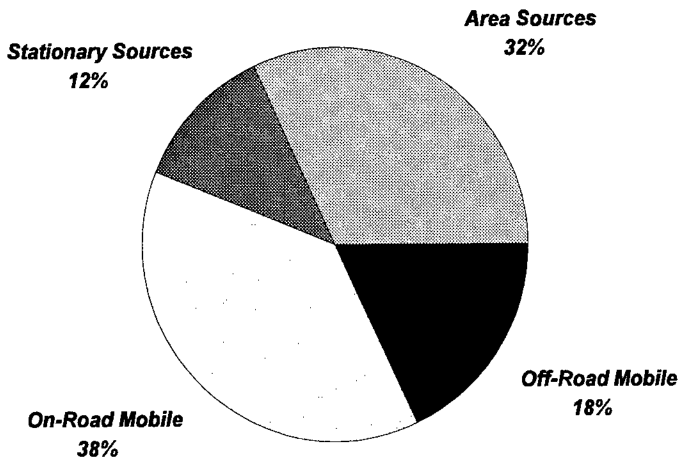


FIGURE 1-1. 1990 VOC emissions sources: D/FW nonattainment area (8)

REPORT STRUCTURE

This report is organized into four chapters. The first chapter has provided a thorough explanation of the impetus for the work documented in this report. Chapter II details the study design and the sites selected for the case studies. The third chapter presents the results of the case studies. Finally, Chapter IV discusses the conclusions drawn from the data analysis and observations in the field.

CHAPTER II. STUDY DESIGN

This chapter outlines elements of the study design. It includes a discussion of the site selection criteria, a discussion of the activity measures identified for later analysis and emissions estimation, and a brief discussion of fuel classification to show its importance in the emissions analysis. The chapter concludes with a description of each selected study site.

SITE SELECTION CRITERIA

The research team used several criteria to select study sites for this project. These criteria were: location within the metropolitan area, level of construction activity, variety of construction activities, cooperation of the prime contractor, and deployment on the site. An explanation of each of these criteria follows.

Location Within D/FW Metropolitan Area

The research team selected sites within the D/FW metropolitan area. The North Central Texas Council of Governments (NCTCOG) is the agency responsible for programming transportation improvements to meet regional transportation needs within federal air quality guidelines. In 1997, Dallas-Fort Worth was classified as a moderate nonattainment area for ozone. There are several highway capacity improvement projects under construction in the D/FW metropolitan area, as well as routine maintenance activities on several roadways. This made choosing specific locations for this study a simple task.

Level of Construction Activity

The research team selected heavy highway construction projects for observation in this study. The team selected this level of construction activity because these types of projects typically include the use of more and larger machinery, and have a sufficient level of equipment activity to record. In addition, the team selected one maintenance project for observation. This site provided the research team with activity details associated with routine maintenance projects.

Variety of Construction Activities

The research team sought a variety of activities for observation. This activity variety provided the research team with samples of activity for similar construction tasks, and, if possible, provide a basis for comparison.

Cooperation of Prime Contractors

Assistance from each of the prime contractors at the data collection sites was requested through the TxDOT construction field offices. The prime contractors were asked to provide a list of equipment on-site, hours of operation for each piece of equipment, estimated production from the equipment, and a list of chemicals used on-site.

Deployment on the Site

Data collection plans included deploying an observation team at each site to provide adequate coverage of construction activity. Site deployment was based on three priorities. First, the highest priority was safety of the observation team. Safe areas at each construction site were selected for the location of the observers. The safe areas were chosen to remove observers from any potential dangers at the construction site and to eliminate hazards associated with passing vehicle traffic.

Deploying observers with little or no interference to the contractor's daily activities was the next priority. This was important so that the observation team did not disturb the normal daily activities at the study sites. Reducing the observation team's interference with construction activities also helped alleviate any potential safety concerns for the observation team.

The third priority was the visual collection of data from each construction activity. The team deployed observers in areas that afforded a maximum view of the construction zones and activities so observers were not limited by physical barriers, such as horizontal or vertical curves. This priority would provide the research team with as much coverage of each construction site as possible given staff and safety limitations.

ACTIVITY MEASURES/OBSERVATIONS

Construction equipment and its respective activity was observed and recorded at each of the construction study sites. The team initially classified equipment into one of three categories. Equipment activity was measured and recorded through four activity measures for each piece of observed construction equipment. First, the engine hours of use are the primary factors in estimating emissions from construction equipment. Second, the number of engine starts provides an indication of cold or hot starts and associated increased emissions. Third, engine throttling in terms of frequency and duration provides some indication of the load placed on an engine. Engine throttling is the visible emissions from the equipment's exhaust pipe. Finally, observers recorded equipment-refueling activities. Specifically, the frequency and duration of these refueling events provided the team with an estimate of evaporative emissions at the construction site.

Equipment Categories

Construction-related equipment was grouped into three categories. The categories included field trucks, material trucks, and construction equipment.

- *Field trucks* are light duty gasoline and diesel trucks used by contractors to move about the construction site. These trucks are used by superintendents, foremen, and maintenance crews throughout the construction site to manage crews, move materials, and conduct other daily activities.
- *Materials trucks* are those vehicles used to transport materials to or from the

construction site. Examples of vehicles in this category are trucks transporting concrete to the site, dump trucks taking soil from an excavation site, trucks removing demolished structures, and trucks delivering other materials to the site.

- *Construction equipment* includes typical construction equipment such as generators, cranes, loaders, tractors, and other items typically found on a construction site.

Engine Hours of Use

The most important data needed for estimating emissions production from construction equipment are the engine hours of use. This information, collected from each piece of equipment, is an important factor in producing construction site engine emissions estimates. The hours of engine use are collected by observing when equipment engines were started and stopped. In some cases, the data was supported or validated against information from the prime contractor on the study day.

Engine Starts

The observation team attempted to collect engine start information at each of the five construction sites. Researchers believed this information would provide some indication of the amount of engine start events associated with certain types of construction activities.

Throttles/Enriched Events

Throttles represent enriched events of equipment operation. Drawing a parallel to recent findings in automobile emissions research, it is believed that a significant increase in equipment emissions results from the transient operation of the equipment similar to the results seen in the transient operation of automobiles. Observers recorded the frequency and duration of equipment throttles at each site to gauge the loads placed on engines. The observation teams used visual or audible signals from each piece of equipment to record throttling activity. The visual signals were visible particulate matter from the engine's exhaust pipe. Observers used audible signals when they were close enough to the activity to distinguish changes in the engine pitch.

Frequency

Observers recorded the throttle frequency during operation of individual pieces of equipment. It was believed that significant throttling events would occur at intensive construction operations such as earthwork or elevated structural work. The research team believed that the greater the frequency of throttles, the more transient the operation.

Duration

It was believed that durations would be short with very few extended throttling events. This represents moderate to intensive loads being placed on engines due to oscillating or back and forth movements. The duration of the throttle is an important factor in determining the average load in relation to rated power of the equipment. This provides a more accurate measurement of emissions production from each piece of equipment.

Refueling

The observation team recorded equipment refueling at the study sites throughout the day. Refueling is a source for evaporative emissions due to the transfer of the fuel from one container to another. These evaporative emissions consist primarily of HC that are precursors to the formation of ozone. The observers recorded the frequency and duration of refueling for analysis.

FUEL CLASSIFICATION

It is important to classify the fuel source for each piece of construction equipment because emissions rates are dependent upon the fuel source used. Fuel sources for construction equipment and field trucks are detailed below.

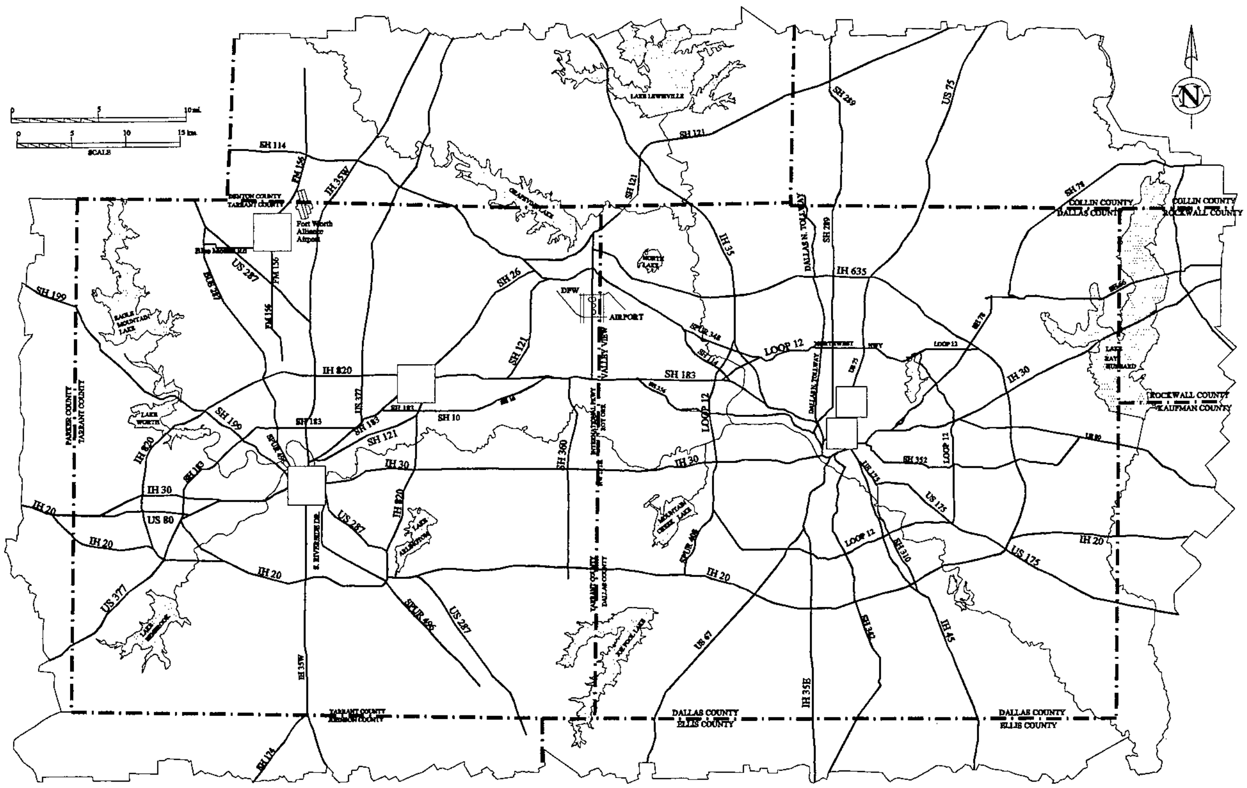
Construction equipment typically uses two fuel types: gasoline or diesel. Most large construction equipment use diesel fuel. Smaller construction equipment, such as small portable generators, typically use gasoline as its fuel source.

Contractors use one of three types of fuels in the field trucks (light duty trucks) they operate for travel around the construction site. These fuel types are gasoline, diesel, and alternative or clean. Clean-fueled vehicles can run on compressed natural gas (CNG), liquefied natural gas (LNG), or ethanol. Field trucks used by contractors are typically fueled by gasoline or diesel. Government trucks are more likely to use clean fuels or a dual-fuel system.

DESCRIPTION OF SITES SELECTED FOR OBSERVATION

The research team selected five sites for observation in the D/FW metropolitan area. The study sites were contained within Dallas and Tarrant counties. These counties were selected from the NCTCOG region because they represent the most urbanized counties, and include more urban freeway miles than surrounding counties. These counties also contain a majority of the major reconstruction sites in the D/FW area.

Two urban freeway sites were selected in Dallas County along US 75 (Central Expressway). In Tarrant County, three sites were selected: I-35W/I-30 interchange, I-820 interchange, and a section of FM 156. Figure 2-1 shows the two-county area and the relative location of each study site. A detailed description for each of these sites follows.



Case Study Location

FIGURE 2-1. Study Site Locations in the D/FW Metropolitan Area

North Central Expressway (NCE)

North Central Expressway (US 75) is a primary north-south corridor in Dallas, Texas. This roadway connects the Dallas Central Business District (CBD) with several dense office developments to the north in Richardson and Plano, and new office and industrial developments in McKinney. Sections of this highway have been under reconstruction since the mid-1980s (beginning with sections in Plano and Richardson at the northern end of the urbanized freeway segment).

The team collected data at the two southern sections of this construction site during the summer of 1997. These construction contracts each generated about $1 million of billing per month (12). An attractive factor for selecting these two sites was that they were both managed by the same prime contractor. This assisted in coordinating data collection.

The mainlane movement along these two sections is very restricted. The mainlanes consist of a four-lane section with concrete barriers on the left and right side of the travel ways, except in sections where work is complete on the final outside wall. The temporary entrance ramps are typically short in length with limited sight distance. These attributes contribute to congestion during moderate to heavy mainlane volumes, as vehicles entering the freeway will come to a complete stop prior to merging onto the mainlane. Nonrecurring congestion through these two sites typically results in capacity reductions of 50% because there are no areas for vehicle evacuation to relieve queued demand. The frontage road system for the two North Central Expressway sites is complete.

The reconstructed sections at these locations are unique in that sections of the frontage roads are cantilevered over the mainlanes. The cantilevered sections make construction more time consuming than the construction of an ordinary retaining wall. The entire section of mainlanes here are typically depressed, and with the amount of adjacent development, cantilevered sections are the most appropriate method to accommodate the demand along the frontage roads.

Solar-powered, not gas-powered, changeable message signs are used at both sites. Other voluntary actions include a reduced duration of lane closures and a limitation of small engine use. Lane closures normally occurred between the hours of 9:00 a.m. and 3:30 p.m.; however, on Ozone Action Days, lane closures cannot occur until after 10:00 am. This one-hour delay is imposed to further reduce impacts on traffic until after the favorable hours for ozone formation.

The research team labeled the southern section S-1 and the section immediately to the north was labeled S-2. Both of these sections are described in further detail below.

NCE S-1

This 2.4-mile project connects US 75 to I-45 and Spur 366 (Woodall Rogers Freeway) at the northeast corner of the Dallas CBD (Figure 2-2). The site is constrained on the east and west sides of the highway by development. The section is also constrained by the heavy volume of traffic, which use the facility.

The research team observed this project during early phases of the construction schedule. Most of the construction work observed consisted of earthwork. The team observed some concrete placement work.

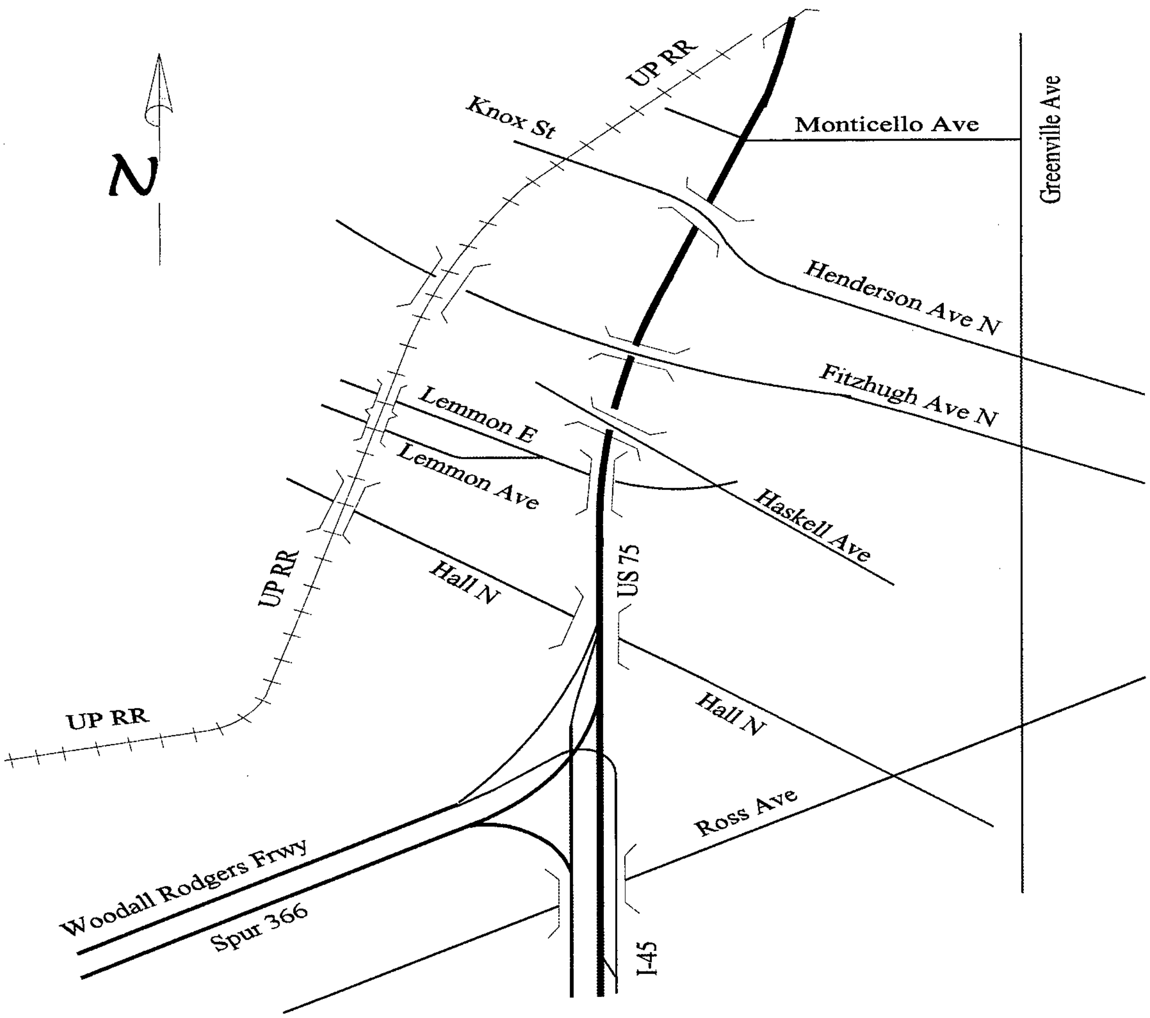


FIGURE 2-2. Schematic of the NCE S-1 Study Site

NCE S-2

This 2.1-mile project is located immediately north of the S-1 project. Figure 2-3 is a schematic of this construction site. This project is also constrained by development on each side of the highway and the heavy traffic along North Central Expressway.

The team observed this site when it was approximately 80% complete (9). Much of the construction activity observed along this section was pavement placement, curb placement, and other finish-out activities.

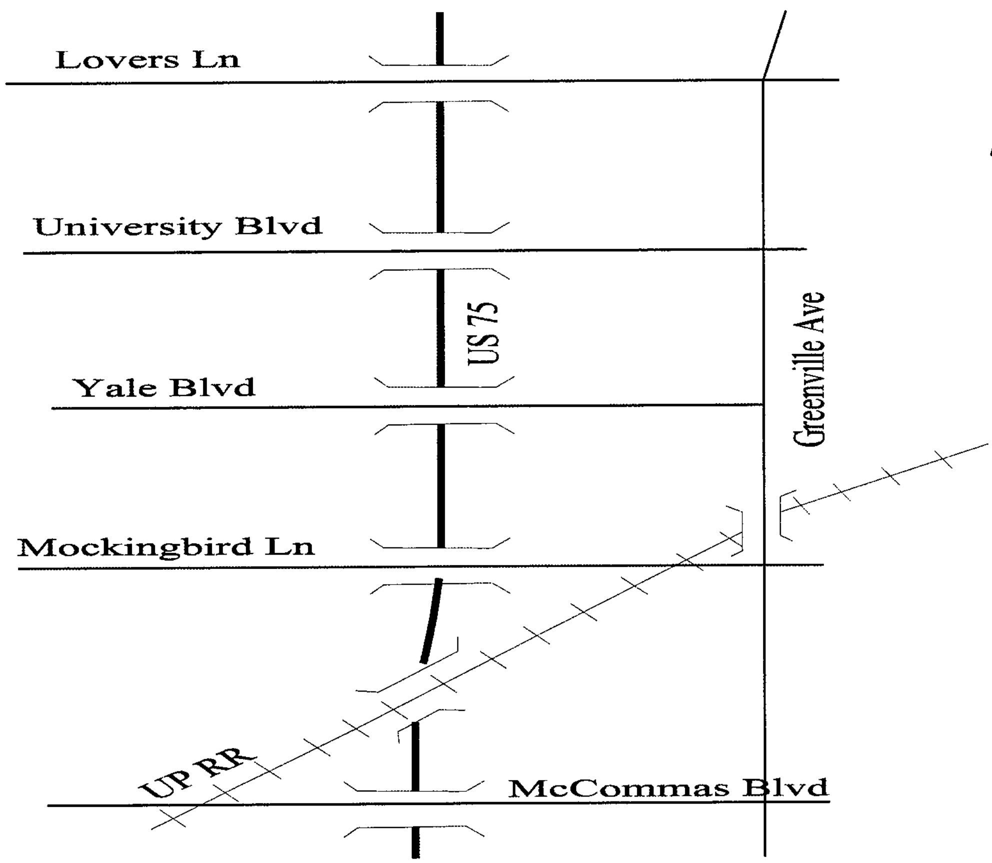


FIGURE 2-3. Schematic of the NCE S-2 Study Site

Fort Worth Mixmaster (I-35W/I-30)

The I-35W/I-30 interchange in Fort Worth is often referred to as Fort Worth's "Mixmaster". The mixmaster is located at the southeastern corner of the Fort Worth CBD. The construction site is located at the intersection of I-35W, I-30, and US 287, the major freeways serving the downtown area (Figure 2-4).

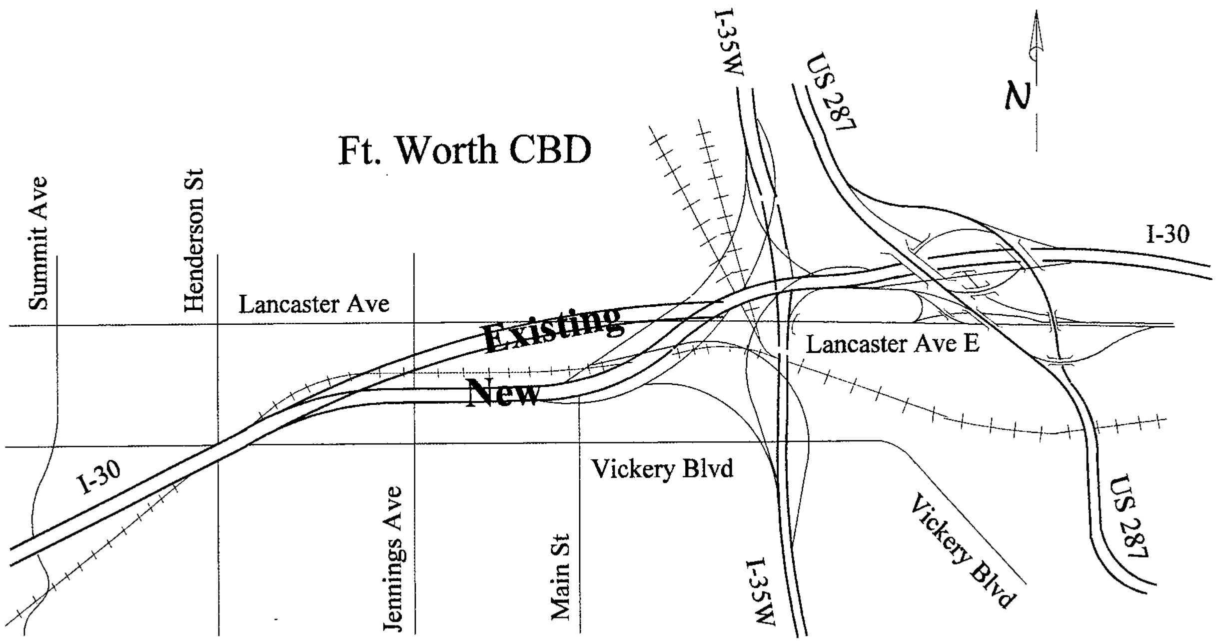


FIGURE 2-4. Schematic of the I-35W/I-30 Study Site

This construction project was divided into eight segments as summarized in Table 2-1. Some segments are complete, others are under construction, and several segments have not been let for construction.

The East Incremental segment connects I-30 and US 287, and some of the I-30 mainlanes between the US 287 interchange and the I-35W interchange. The South Incremental segment project rebuilt some of the frontage roads on I-35W south of I-30 and some of the overpasses for the cross streets. The Summit/8th Avenue segment work rebuilt the western parts of the frontage road along I-30 at the edge of the Fort Worth CBD and included the construction of an overpass for Summit Avenue.

The West Incremental segment was the segment observed for this study. The work on this segment included construction of new I-30 freeway lanes south of the current I-30 mainlanes along Lancaster Avenue. The segment also includes elevated structures leading up to the primary interchange of I-35W and I-30. Additionally, the construction of some frontage road and ramp structures, as well as mainlane construction, was included along I-35W north of the I-30 interchange.

Construction of the Summit to Hemphill segment will enable new I-30 mainlanes south of the current I-30 mainlanes to provide a connection between existing I-30 mainlanes west of the CBD to the new mainlanes leading to the reconstructed I-30/I-35W interchange. The Central Increment segment will include the construction of the directional I-35W/I-30 interchange, including connections to each of the freeways and mainlanes through the interchange. The West of Summit to Summit segment will rebuild the existing I-30 mainlanes west of the CBD to the Trinity River. Finally, the Lancaster & Connection segment will complete this multi-million dollar project by providing city street connections to the new I-30 frontage road system and existing express lanes along Lancaster Avenue.

TABLE 2-1

I-35W/I-30 CONSTRUCTION SEGMENTS

Segment	Contract Amount	Construction Starting
East Incremental	$19M	
South Incremental	$14M	
Summit/8th Ave	$9M	
West Incremental (Observed)	$31M	
Summit to Hemphill	$24M	
Central Increment	$43M	1998
West of Summit to Summit	$7M	1998
Lancaster & Connection	$10M	2000

The construction segment observed was located south of the current I-30 mainlanes as stated previously. The new location for the mainlanes is away from current I-30 traffic and therefore did not adversely impact observers.

Northeast Loop Interchange (I-820 NE)

The Northeast Loop Interchange is located at the northeast corner of the I-820 loop around the city of Fort Worth. Figure 2-5 is a schematic of this construction site.

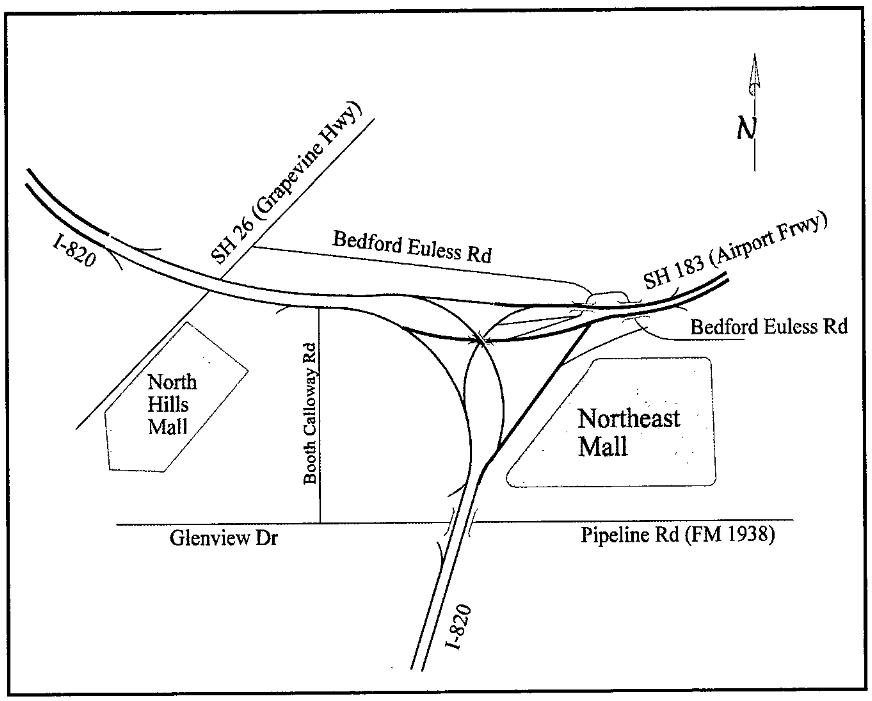


FIGURE 2-5. Schematic of the I-820 NE Study Site

At this interchange, several state highways and state maintained roads converge: SH 26, SH 183, FM 1938, and I-820. SH 183 is a major east-west corridor which connects northern Fort Worth to the D/FW International Airport and Dallas. SH 26 is major arterial which connects many suburban areas in the northeast section of Tarrant County to-I 820. Regional shopping malls, Northeast Mall and North Hills Mall, are located at or near the project site. A number of other high visibility and high-traffic commercial establishments are located around the project site to the north, west, and east.

Traffic along the three legs of this interchange is particularly heavy since it provides a connection between north, east, and central Fort Worth with northeast Tarrant County, D/FW International Airport, Dallas, and surrounding cities north of Dallas. Traffic is also heavy here due to the large retail centers adjacent to a large portion of the construction site. The project site consists of four phases. The contract amounts for each construction phase are shown in Table 2-2.

TABLE 2-2
I-820 NE CONSTRUCTION PHASES

Phase	Contract Amount
Phase 1	$17M
Phase 2 (Observed)	$18M
Phase 3	$35M
Phase 4	$21M

Following are details of the four phases:

- Phase 1 of this project focused on the infrastructure at the west edge of the project limits. Crews reconstructed the I-820, SH 26, FM 1938, and Bedford-Euless Road interchanges. Retaining walls are in place and new pavement is on the ground.
- Phase 2 of the project, observed as part of this research project, included reconstruction of the I-820 and Glenview Drive/Pipeline Road and SH 121 and Bedford-Euless Road interchanges. Work also included the reconstruction of frontage roads on the east and west sides of the project site. Phase 3 work consists of constructing the new internal infrastructure elements of the interchange. This includes the construction of several overhead ramps along with new mainlane pavements along the SH 121 - I-820 westbound lanes.
- Phase 4, the final phase of the project, will include the construction of the ramp linkages for FM 1938 to and from I-820. Additionally, it will include the construction of the

remaining few internal ramp linkages with the frontage roads on the west and east sides of I-820 at Glenview Drive and Pipeline Road.

FM 156

A section of FM 156 in northwest Tarrant County was the only light activity construction site selected for this study. The project site extended from US 287 in northwest Tarrant County to the Tarrant-Denton county line, a distance of 8.875 kilometers. Figure 2-6 is a schematic of the project site and surrounding area. The research team sought to collect data representing routine maintenance activities for asphalt pavement since these are typically routine summer construction activities. Crews typically perform these maintenance activities on short segments of roadway to minimize traffic disruption.

FM 156 connects Alliance Airport and the Alliance Intermodal Facility with US 287 to the south. These generate a large amount of truck traffic from transporting goods from the air and rail modes to the more mobile truck mode. This is primarily a two lane roadway, except through the town of Haslet. It is located in a primarily rural part of the county and provides residents a connection to the Fort Worth metropolitan area. Other than passenger vehicle traffic, the roadway is used by commercial trucks carrying loaded and unloaded freight boxes to and from the Alliance Airport and the Alliance Intermodal Facility.

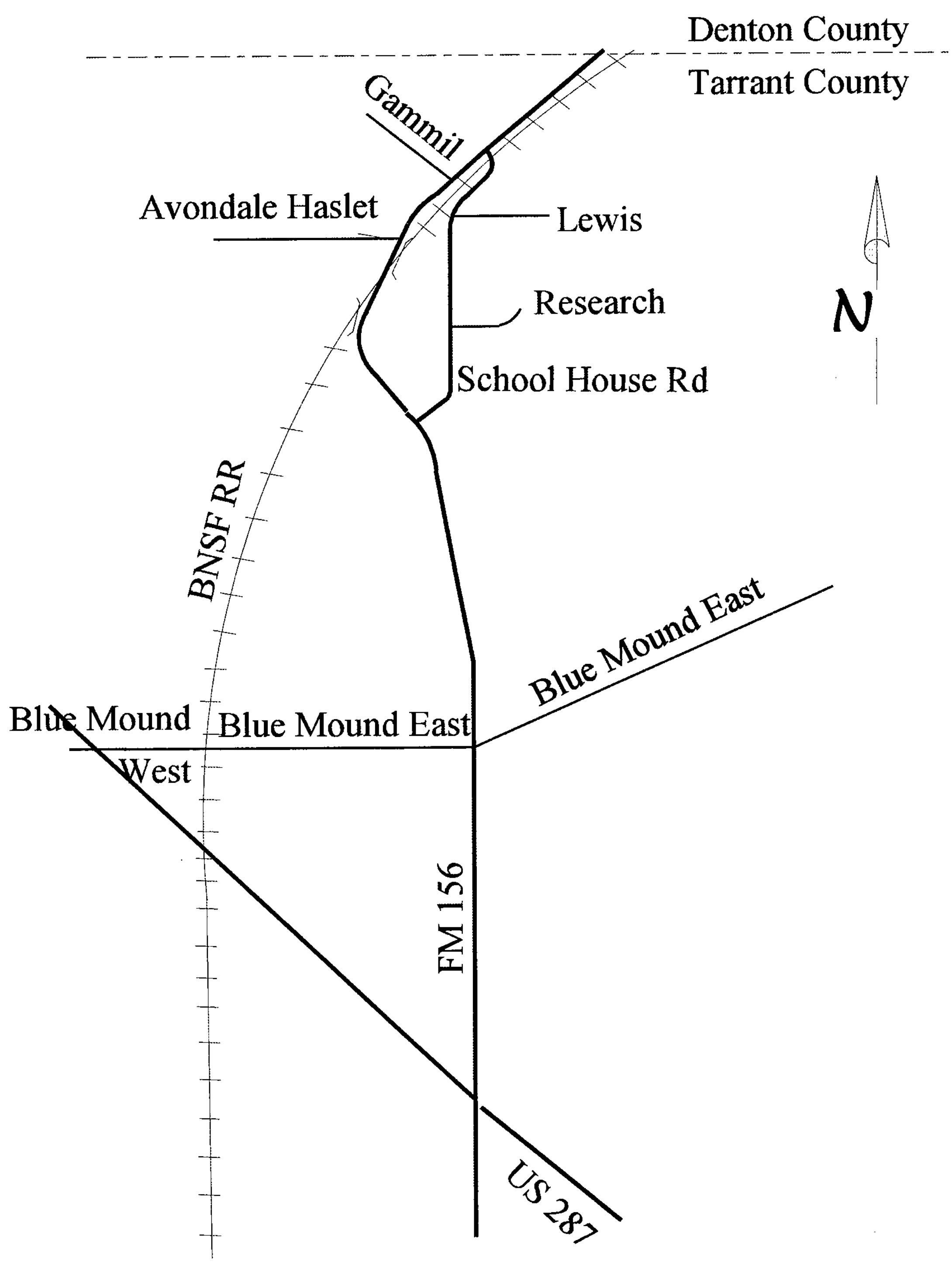


FIGURE 2-6. Schematic of the FM 156 Study Site

CHAPTER III. RESULTS

The research team collected a wide range of data from each of the highway construction study sites. As discussed in the previous chapter, the team recorded all observed construction activities. This includes activity measures such as equipment usage in terms of engine hours of operation, the duration and frequency of observable throttles, and all other recorded visual observations.

CONSTRUCTION ACTIVITY OBSERVED

The team observed a variety of construction activities at each study site. The observed activities ranged from elevated slab placement to demolition of existing pavements to soil compaction. Following is a detailed discussion of the activities at each of the five study sites.

Site 1: NCE S-1

The activity observed at this site is typical of early phases in a heavy highway construction project. At the southern end of the site, activity consisted of material loading and earthwork at the connecting interchange. This earthwork included soil compaction and fill at the approach of an exit ramp, and grading and compaction along the portions of the future southbound mainlanes. At Hall Street, workers had placed concrete on two sections of the overpass. There was activity under Hall Street in the southbound mainlanes, however this activity was beyond the view of the observers and was further complicated by shadows from the Hall Street overpass.

Immediately south of the Lemmon Avenue overpass, workers added and mixed lime into the mainlane subbase. They also completed some coarse grading work along this area. To the north of the Lemmon Avenue overpass, several activities were underway. First, two backhoes were performing some minor excavation. Workers were also using track drills to drill for the retaining wall tiebacks. Additionally, equipment was being delivered from another location on the project site.

Observers found some drilling south of Haskell Avenue on the northbound side. Workers were unloading reinforcement bars at a staging area located on the east side of the Haskell Avenue intersection. The concrete batch plant for this project, and for the project immediately to the north, was located north of the Haskell Avenue intersection on the east side.

The team observed excavation activity in the southbound mainlanes immediately south of the Fitzhugh Avenue overpass. To the north, workers were excavating in the southbound lanes.

At the Knox Street/Henderson Avenue overpass, the team observed construction on overpass columns. Workers were using a crane to hoist and hold the concrete forms in place while they adjusted and attached them together. Between the Knox Street/Henderson Avenue area and Monticello Avenue, workers established a material staging area in the northbound section.

At Monticello Avenue, the team observed a variety of activities. On the northwest side of the intersection, they found construction activity at the cantilever section. In the northbound lanes under the overpass, workers were tying reinforcement bars, and a bumblebee screed used during concrete placement was delivered to the site.

Other activities, not limited to one particular location, included maintenance activities and dust control. Maintenance crews typically move through the site at the end of each day refueling and checking construction equipment. Workers used a sweeper to control dust from construction and other litter and debris at the site.

The team observed almost all this study site's activities. Observations that were not made, or were missed, included the contractor's field office yard. Workers refueled some equipment, and moved and organized on-site material at this location.

Site 2: NCE S-2

At McCommas Boulevard, the team observed concrete wall painting and sidewalk demolition. Workers used a lift to paint retaining walls along the southbound mainlanes. Using a ram hoe, they ripped up sidewalks at the northwest corner of the intersection of the southbound frontage road. Workers then transported this material to the southwest corner of the intersection where they used some of the material to fill areas for future sidewalks.

There was considerable activity between Mockingbird Lane and McCommas Boulevard in the southbound mainlanes. Although this activity was not equipment intensive, the team observed workers placing reinforcement bar on the inside shoulder, organizing construction materials, and using an air compressor to clean a formed pavement section.

The team observed excavation activity in the southbound mainlane area south of the Yale Boulevard overpass. At this location, a track hoe would excavate dirt while a bulldozer would move the dirt into piles. A front-end loader would then load the excess soil into materials trucks to transport the soil either away from the site or to another location. Also in this area, a crane and motor grader were performing typical activities. Between Yale Boulevard and University Boulevard, workers moved shoring south along the wall for the southbound mainlanes. Workers used a generator on the frontage road level.

The team also observed the placement of a small, elevated concrete slab on the southwest corner of the University Boulevard overpass, and the placement of reinforcing bar on the northwest corner. Workers placed precast concrete wall panels along the southbound mainlanes north of University Boulevard.

Other activities, not limited to one particular location, included maintenance activities and dust control. Maintenance crews typically move through the site at the end of each day refueling and checking construction equipment. Workers used a sweeper to control dust from construction and other litter and debris at the site.

Two observations resulted from the team's visit to this site. First, construction was at a stage where the number of activities had dropped, but the remaining tasks were of longer duration (8). Second, most of the construction activity at this site ceased after 3:00 p.m.

The team observed almost all this study site's activities. Observations that were not made, or were missed, included the contractor's field office yard. Workers refueled some equipment, and moved and organized on-site material at this location.

Site 3: I-35W/I-30

At the time the team observed this construction site, construction activity did not affect any streets other than the local streets in the immediate vicinity of the project. These streets provided access to numerous areas along the construction project.

The primary activity observed was the placement of an elevated concrete slab immediately west of Main Street. This activity began prior to 3:00 a.m. and continued into the early morning hours (after 7:00 a.m.). This very intensive activity requires the use of several fuel-powered pieces of equipment. Workers used several light plants to provide adequate lighting for the early morning work. They also used small portable generators to power portable vibratory equipment. Workers used a concrete pump truck to transport the concrete from the ground to the elevated deck overhead. They used a concrete paving machine to even out and rough finish the pumped concrete. Following the paving machine were two other machines that used small engines to propel them the length of the section.

At the west end of the construction site, west of Jennings Avenue, workers re-mixed lime into the subbase for several hours in the afternoon. Other activities observed throughout the site included routine maintenance on lattice boom cranes under the new IH-30 elevated mainlanes, material transport/organization throughout the study site, and grading activity along the railroad right-of-way south of Vickery Avenue.

The team observed almost all this study site's activities. Observations that were not made, or were missed, included the contractor's field office yard. Workers refueled some equipment, and moved and organized on-site material at this location.

Site 4: I-820 NE

This site also provided a wide range of activities for observation. At Glenview Drive/Pipeline Road, the team observed several activities with the bulk of the activity being performed on the observation day. Workers were installing and compacting fill along the retaining wall on the east side of the northbound approach to the I-820 overpass, while other workers focused on building the approach to the south header wall. Under this overpass, the team recorded several activities. Workers were excavating on the west side and trenching for electrical conduits in the center of the underpass. The team also observed grading on the north side of this overpass and along a portion of the future northbound frontage road.

Workers were pouring rip rap on the south side under the Glenview Drive/Pipeline Road overpass. Other workers were using a welding machine and a small generator to attach the permanent metal decking to the overpass. Additional workers were constructing the temporary walls on the northeast side of this overpass.

The team also observed a number of activities around the SH 183/121 overpass at Bedford-Euless Road. On the south side of this overpass, workers placed curbing, and under the overpass and to the south, workers demolished the existing asphalt in the inside southbound lanes. In addition, workers used scissor lifts to inspect the finishing work on columns and the underside of the overpass deck. To the north of this overpass, workers were fine grading the median of Bedford-Euless Road. Slightly farther north of this activity, workers demolished additional asphalt pavements.

The team observed almost all this study site's activities. Observations that were not made, or were missed, included the contractor's field office yard. Workers refueled some equipment, and moved and organized on-site material at this location. From a distance the team observed some equipment transfer in the temporary median of SH 183/121, but accurate measurements of this activity was not recorded.

Site 5: FM 156

The construction activity observed at this site occurred on a short section of the project in Haslet. The section runs between Gammil Street to the north and School House Road to the south. The activity section includes a railroad crossing in the southern half of the study area.

The construction activity consisted of overlaying asphalt along the northbound and southbound lanes of FM 156. The contractor was performing a Type D surface polish. The team scheduled data collection on three different days due to a rain out, and mix design problems. The shoulder in Haslet is 10 feet wide, and is 4 feet wide outside of Haslet. The materials trucks were dispatched from an asphalt plant in Justin, eight miles from the project site. This site had the fewest pieces of equipment of any of the study sites. Equipment found at this site included an asphalt laydown machine, two steel drum rollers, a pneumatic roller, a distributor or tack truck, and a small bobcat loader. This operation can typically place 1600 to 2000 tons of asphalt per day (10).

Workers previously completed the overlay on the outside shoulder and the team only observed activity on the FM 156 mainlanes. This was a two-lane section. As work progressed on one side of the roadway, workers used the one open lane for diverting traffic around the construction activity. Overlay work began at the north and moved south, skipping a short segment at the railroad crossing, then continued south to School House Road. Overlay work then proceeded to the northbound side and ended where the activity had begun for the day.

OZONE MEASUREMENTS

Table 3-1 indicates when the team observed the five study sites, temperature ranges for the observation day, and ozone measurements made for the region on that day. Additionally, the table indicates whether ozone action days were called the day prior to, the day of, or the day after the observation day.

TABLE 3-1
REGIONAL METEOROLOGICAL INFORMATION

County	Site	Study Date	Temperature (°F)		Ozone (PPM)	Ozone Action Day		
			High	Low		Prior	On	Next
Dallas	NCE S-1	July 29, 1997	101	80	139	Y	Y	N
	NCE S-2	August 1, 1997	93	73	115	N	Y	Y
Tarrant	I-35W/I-30	August 15, 1997	97	78	54	N	N	N
	I-820 NE	August 18, 1997	95	77	70	N	N	N
	FM 156	October 22, 1997	64	49	36	N	N	N

The first day of observation for this study coincided with the first day of temperatures greater than 100 °F. In the afternoon, severe thunderstorms from the north brought excessive wind gusts and torrential rain to the region. The last observation day was windy and cool. The remaining days when the team observed the study sites were clear.

EQUIPMENT SUMMARY/HOURS

The inventory of construction equipment at each site is summarized in Table 3-2. The number of pieces of equipment observed at each site increased as the construction size and complexity increased. This is a common fact. The distribution of equipment among classes better describes the type of work performed on the site. The site exhibiting the most activities from the most number of pieces of equipment is NCE S-1. Following this reasoning, the FM 156 site should have the least activity because it has the fewest pieces of equipment. More earthwork activities are expected at the NCE S-1 site because it had the highest number of truck-type tractors, motor graders, wheeled loaders, and rollers than any other observed site. Site observations corroborate this statement. To better gauge activity, supplement equipment totals analysis with engine hours of use.

TABLE 3-2
EQUIPMENT INVENTORY BY AP-42 CLASS

AP-42 Class	NCE S-1	NCE S-2	I-35W/I-30	I-820 NE	FM 156
Track-Type Tractor	3	1	2	1	--
Wheeled Tractor	--	--	--	--	--
Wheeled Dozer	--	--	--	--	--
Scraper	--	--	--	--	--
Motor Grader	6	1	1	1	--
Wheeled Loader	20	12	2	4	1
Track-Type Loader	--	--	--	1	--
Off-Highway Truck	9	4	4	3	4
Roller	6	--	2	1	5
Misc	23	19	14	9	1
TOTAL	**67**	**37**	**25**	**20**	**11**

NOTE: – None observed

After reviewing the observed engine hours, the relationship between activity and the number of pieces of equipment becomes less credible. As seen in Table 3-3, the lowest activity site remains FM 156 and the highest activity site remains NCE S-1. However, there is no discernable relationship between the characteristics of the three remaining sites. A gap in the data may clarify any statements made regarding site size and complexity to the number of pieces of equipment and engine hours of use. The data in Figure 3-1 represents each of the study sites in relation to the total number of pieces of equipment and engine hours of use observed. As expected, engine hours increase as the number of pieces of equipment increases at a site.

TABLE 3-3
OBSERVED ENGINE HOURS OF USE BY AP-42 CLASS

AP-42 Class	NCE S-1	NCE S-2	I-35W/I-30	I-820 NE	FM 156
Track-Type Tractor	16.52	7.32	0.98	6.73	--
Wheeled Tractor	--	--	--	--	--
Wheeled Dozer	--	--	--	--	--
Scraper	--	--	--	--	--
Motor Grader	19.18	0.05	6.21	7.14	--
Wheeled Loader	40.51	25.1	9.67	19.78	2.42
Track-Type Loader	--	--	--	5.8	--
Off-Highway Truck	7.73	3.97	8.59	7.53	11.45
Roller	26.57	--	5.8	6.99	34.21
Misc	54.83	42.12	42.11	28.81	12.52
TOTAL	**165.34**	**78.56**	**73.36**	**82.78**	**60.6**

NOTE: – None observed

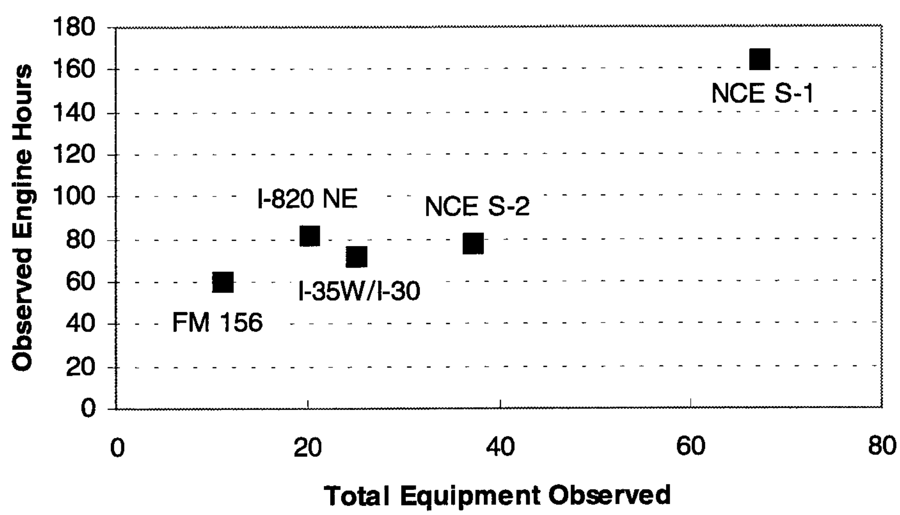


FIGURE 3-1. Total Equipment Observed vs. Observed Engine Hours of Use by Study Site

FIELD TRUCKS

Field trucks are light duty diesel, gasoline, or low emissions (natural gas or other) pickup trucks used by the contractor or TxDOT personnel to travel around the construction site. Data collected in the field included engine on/off times (translates to the number of cold-and hot-starts and the total engine run time), truck model year, model type, initial odometer reading, and fuel type.

Table 3-4 shows the distribution of field trucks observed by their fuel source. Contractors use conventionally-fueled field trucks with a majority of these being diesel fueled. The team observed, however, an even split between conventional gasoline-fueled field trucks and clean- or dual-fueled trucks driven by TxDOT personnel. The higher occurrence of clean- or dual-fueled field trucks at TxDOT is a result of mandates and clean air goals adopted by government.

TABLE 3-4
FUEL SOURCE DISTRIBUTION FOR OBSERVED FIELD TRUCKS

Fuel Source	Contractor	TxDOT
Diesel	24	0
Gasoline	17	10
Clean/Dual	1	9

An analysis of field truck model years, on-site activity, and emissions production is detailed in the following sections.

Model Year Analysis

Analysis of field truck model year distributions yielded very commonsense results. The diesel truck model years showed that the most common model year is 1994, with a majority of model years from the mid- to late-1990s, as shown in Figure 3-2. It is expected that these newer trucks are equipped with recent emissions control technologies, thus helping to curb their emissions.

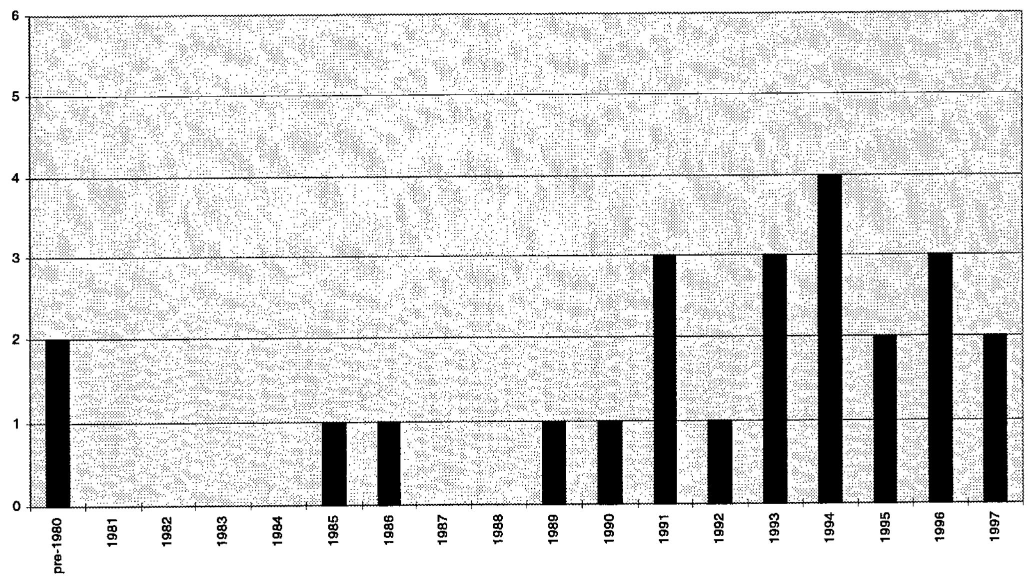


FIGURE 3-2. Model Years of Diesel-Fueled Field Trucks

Figure 3-3 shows that the gasoline-fueled trucks model year distribution was different from the diesel-fueled trucks. Contractors' vehicles were mid- to late-1990 models. The majority of TxDOT vehicles were late-1980s models. The government programs to convert to clean fuel vehicles began after 1990. This is evident from the figure here that shows a decrease in the number of post-1990 gasoline fueled trucks.

Figure 3-4 displays the model year distribution for clean-fueled trucks. A growing number of these TxDOT vehicles were late-1990s models. This increase occurred for the same reason a decrease in gasoline-fueled trucks was seen in the previous figure.

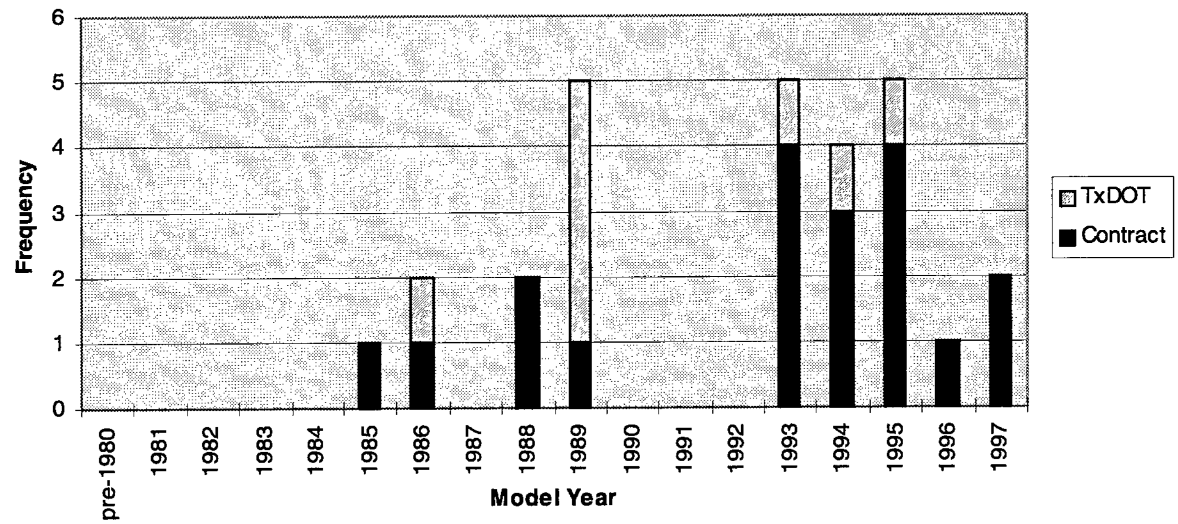


FIGURE 3-3. Model Years of Gasoline-Fueled Field Trucks

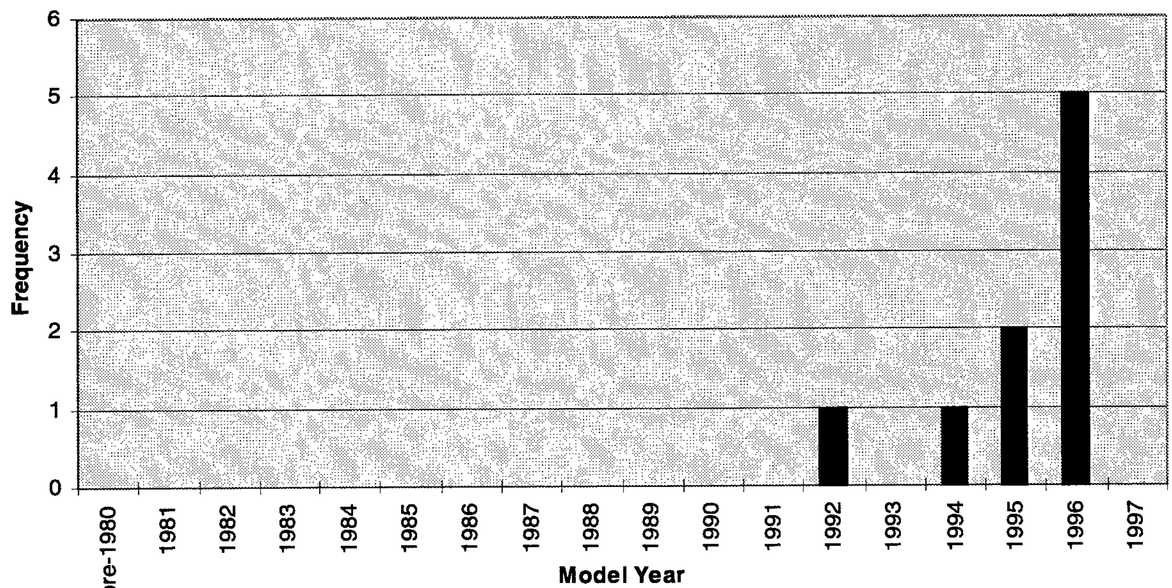


FIGURE 3-4. Model Years of Clean-Fueled Field Trucks

Activity Analysis

The research team collected a significant amount of data from the field trucks at all but two of the study sites. Contractors provided information at each of the five study sites. The team did not obtain any TxDOT field truck activity from the NCE S-1 and FM 156 study sites. Requests for data collection participation were made, but either no data was collected as requested, or the data was not returned for processing and analysis. A summary of the observed activity results at each site for contractors and TxDOT respectively is shown in Tables 3-5 and 3-6. Running times of contractors' field trucks increased as the size and complexity of the construction site increased. No other correlation to site size or complexity was developed from the field truck data observed.

Figures 3-5, 3-6, and 3-7 show the comparison of cold, hot, and total engine starts for contractor and TxDOT vehicles. These figures show that contractors produce 30% to 50% more engine starts than TxDOT staff. The only correlation between engine starts and construction sites is that the larger and more complex a site, the greater the number of field truck engine starts.

TABLE 3-5
CONTRACTORS' FIELD TRUCK ACTIVITY CHARACTERISTICS BY SITE

Activity	NCE S-1			NCE S-2			I-35W/I-30			I-820 NE			FM 156		
	Diesel	Gasoline	Clean	Diesel	Gasoline	Clean	Diesel	Gasoline	Clean	Diesel	Gasoline	Clean	Diesel	Gasoline	Clean
Number of Trucks	10	0	0	9	0	0	4	7	1	1	9	0	0	1	0
Number of Cold Starts	36	--	--	25	--	--	9	22	4	1	25	--	--	5	--
Number of Hot Starts	24	--	--	24	--	--	8	22	0	1	53	--	--	3	--
Running Time (min.)	3202	--	--	3528	--	--	1375	2128	90	484	1778	--	--	50	--
Maximum Cold Starts	5	--	--	5	--	--	3	4	--	--	4	--	--	--	--
Average Cold Starts	3.6	--	--	2.8	--	--	2.3	3.1	4.0	1.0	2.8	--	--	5.0	--
Minimum Cold Starts	2	--	--	1	--	--	1	2	--	--	2	--	--	--	--
Maximum Hot Starts	6	--	--	7	--	--	4	7	--	--	15	--	--	--	--
Average Hot Starts	2.4	--	--	2.7	--	--	2.0	3.1	0.0	1.0	5.9	--	--	3.0	--
Minimum Hot Starts	0	--	--	0	--	--	0	0	--	--	1	--	--	--	--
Maximum Running Time (min.)	524	--	--	680	--	--	470	480	--	--	284	--	--	--	--
Average Running Time (min.)	320	--	--	392	--	--	344	304	90	484	198	--	--	50	--
Minimum Running Time (min.)	190	--	--	170	--	--	185	49	--	--	38	--	--	--	--

-- Not applicable

TABLE 3-6
TxDOTS' FIELD TRUCK ACTIVITY CHARACTERISTICS BY SITE

Activity	NCE S-1[1]			NCE S-2			I-35W/I-30			I-820 NE			FM 156[2]		
	Diesel	Gasoline	Clean	Diesel	Gasoline	Clean	Diesel	Gasoline	Clean	Diesel	Gasoline	Clean	Diesel	Gasoline	Clean
Number of Trucks	0	1	5	0	1	5	0	5	1	0	4	3	0	1	0
Number of Cold Starts	--	1	10	--	1	12	--	12	2	--	10	7	--	5	--
Number of Hot Starts	--	3	20	--	3	18	--	13	8	--	24	11	--	3	--
Running Time (min.)	--	125	550	--	124	538	--	401	242	--	412	349	--	50	--
Maximum Cold Starts	--	--	--	--	--	3	--	4	--	--	4	3	--	--	--
Average Cold Starts	--	--	--	--	1.0	2.4	--	2.4	2.0	--	2.5	2.3	--	--	--
Minimum Cold Starts	--	--	--	--	--	1	--	2	--	--	1	2	--	--	--
Maximum Hot Starts	--	--	--	--	--	7	--	6	--	--	12	5	--	--	--
Average Hot Starts	--	--	--	--	3.0	3.6	--	2.6	8.0	--	6.0	3.7	--	--	--
Minimum Hot Starts	--	--	--	--	--	0	--	0	--	--	0	2	--	--	--
Maximum Running Time (min.)	--	--	--	--	--	208	--	213	--	--	128	147	--	--	--
Average Running Time (min.)	--	--	--	--	124	108	--	80	242	--	103	116	--	--	--
Minimum Running Time (min.)	--	--	--	--	--	52	--	10	--	--	84	80	--	--	--

-- Not applicable
[1] - Activity values imputed from NCE S-2 study site
[2] - Activity values imputed from contractor's activity at same site

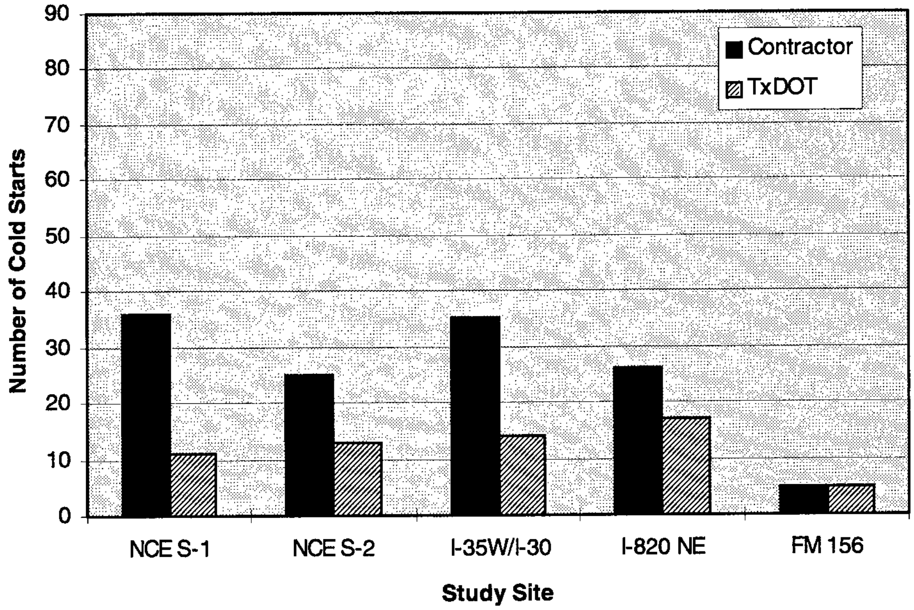


FIGURE 3-5. Field Truck Cold-Engine Starts by Study Site

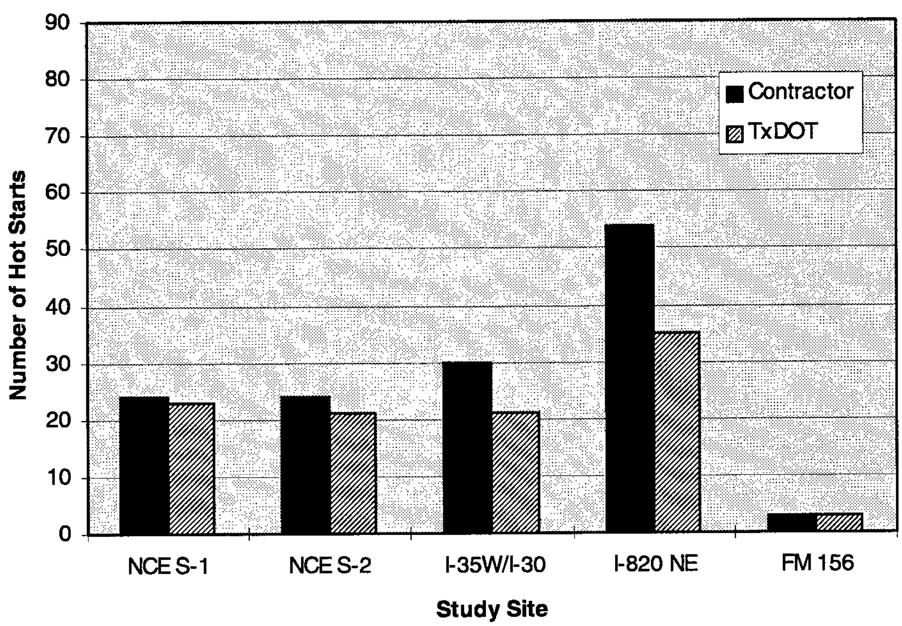


FIGURE 3-6. Field Truck Hot-Engine Starts by Study Site

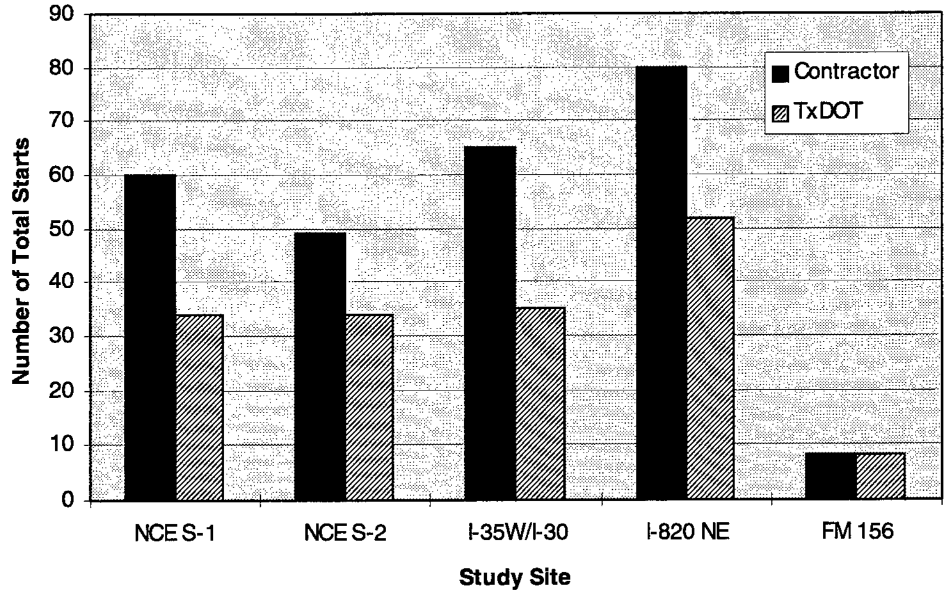


FIGURE 3-7. Field Truck Total Engine Starts by Study Site

Figure 3-8 shows a comparison of the running times for both contractor and TxDOT field trucks. The figure shows that contractors use their vehicles significantly more than TxDOT. In fact, contractors typically have running times 30% to 80% greater than TxDOT vehicles.

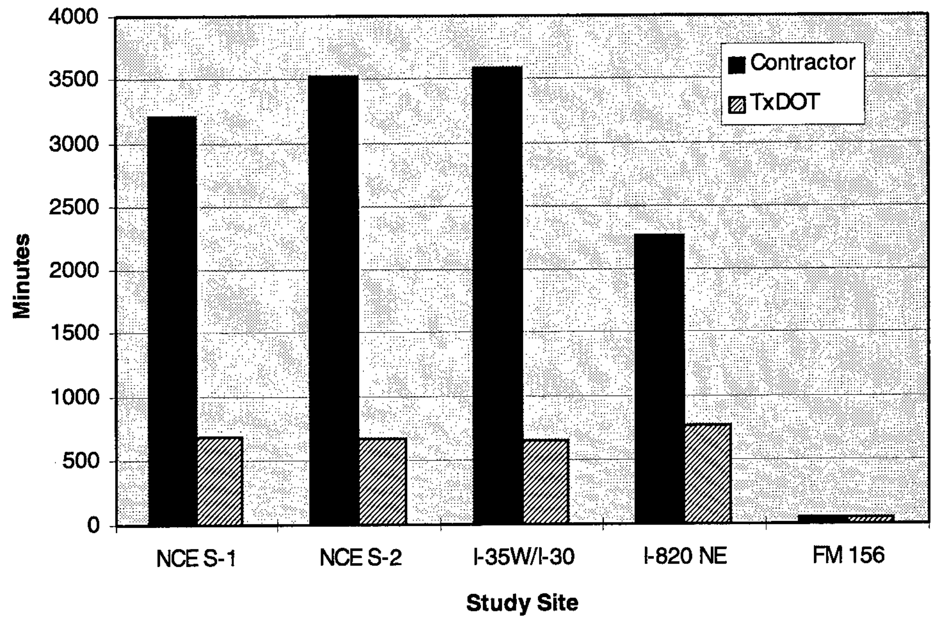


FIGURE 3-8. Field Truck Running Times by Study Site

Table 3-7 shows the average activity values for field trucks based on data collected at each of the study sites. From this table, it is evident that contractors produce a greater number of cold starts than TxDOT, but that both groups produce similar numbers of hot starts on average. Contractors will produce more total engine starts than TxDOT. The contractors are producing more engine starts because they are generating more trips in the construction area than their TxDOT counterparts. The increased number of trips at the construction site results from managing and transporting resources (personnel and materials) to various locations throughout the site each working day. Supervisors may make several trips from the field office to the construction site during the day to manage or inspect work performed by crews.

TABLE 3-7
AVERAGE FIELD TRUCK ACTIVITY SUMMARY

Activity	Contractor	TxDOT
Total Cold Starts	20 - 40	10 - 20
Total Hot Starts	20 - 50	20 - 40
Total Starts	50 - 80	30 - 50
Running Time (minutes)	2,250 - 4,000	650 - 775

TxDOT operates its field trucks 3 to 4 times less than contractors at the same construction site. This large difference in running times is attributed to the functional requirements of field trucks for each group. Contractors use their vehicles to constantly transport and manage resources over the construction site, whereas TxDOT staff use field trucks to inspect portions of the site and may stop to observe construction practices for longer duration times.

Emissions

The research team collected emissions estimates from field trucks using some assumptions and data collected from the field. The activity assumptions were:

Percent of time idle	80
Percent of time running	20
Average running speed	15 miles per hour

The team calculated running and idle emissions using the following equation with assumptions supplied:

*Total Emissions = Idle Emissions Rate * (Total Running Time * Percent of Time Idle) + Running Emissions Rate * [Avg. Speed * (Total Running Time * Percent Time Running)/60]* where,

Idle Emissions Rate =	EPA MOBILE emissions factor for light duty gasoline trucks (LDGT) or light duty diesel trucks (LDDT) as stated in EPA technical documents
Running Emissions Rate =	EPA MOBILE emissions factor for LDGT or LDDT at 15 miles per hour
Avg. Speed =	Average speed of the vehicle (assumed to be 15 miles per hour)
Total Running Time =	Total truck running time observed at the site
Percent of Time Idle =	Percent of time spent idling (assumed to be 20 percent)
Percent Time Running =	Percent of time spent traveling from location to location (assumed to be 80 percent)

EPA's MOBILE5a emissions factor model was the basis for determining emissions rates. EPA supplied guidance for calculating the idle rate. This guidance provides for calculating the idle emissions rate as the emissions factor at 2.5 miles per hour multiplied by a factor to yield an idling emissions rate in grams per hour.

The team used an additional analysis procedure for generating emissions factors from MOBILE for field trucks. This analysis procedure treated clean- or dual-fueled field trucks as gasoline-fueled vehicles. MOBILE does not have the capability to model clean- or dual-fueled vehicles. This analysis results in an overestimation of emissions for clean- or dual-fueled field trucks.

The following sections present and discuss the results of the field truck emissions analysis by study site.

NCE S-1

Table 3-8 shows the emissions analysis results for the NCE S-1 study site. The total emissions from contractors' field trucks are much lower than the estimates for TxDOTs' field trucks. The contractors' field trucks at this study site were all diesel fueled which generally have lower emissions rates for CO, HC, and NOx.

Emissions estimates from TxDOT vehicles followed the assumption that these vehicles would operate similarly to the activity observed at the NCE S-2 study site. Therefore, the TxDOT truck estimates were higher than the contractors' even with less assumed activity. This results from the TxDOT trucks being analyzed as gasoline fueled, when the majority used clean or dual fuel. This assumption causes an overestimation of field truck emissions.

TABLE 3-8
FIELD TRUCK EMISSIONS PRODUCTION AT NCE S-1

Group	Source	Emissions (grams)		
		CO	**HC**	**NOx**
Contractor	Cold Starts	167	67	48
	Hot Starts	75	14	22
	Running/Idle	1,018	431	643
	TOTAL	**1,260**	**512**	**713**
TxDOT	Cold Starts [1]	451	54	36
	Hot Starts [1]	406	54	42
	Running/Idle [1]	3,728	315	112
	TOTAL [1]	**4,585**	**423**	**190**
GRAND TOTAL		**5,845**	**935**	**903**

[1] Activity values were input from data collected at the NCE S-2 study site.

NCE S-2

The total emissions from contractors' field trucks are much lower than the estimates for TxDOTs' field trucks, as seen in Table 3-9. The contractors' field trucks at this study site were all diesel fueled which generally have lower emissions rates for CO, HC, and NOx.

Estimates for the TxDOT trucks were higher than the contractors' even with less observed activity. This results from the TxDOT trucks being analyzed as gasoline fueled, when the majority used clean or dual fuel. This assumption causes an overestimation of field truck emissions. The field truck activity at this site was comparable to that activity observed at its sister site (NCE S-1). Therefore, the estimated emissions from contractors' field trucks at this site are close to the estimates from contractors' field trucks at the NCE S-1 study site.

TABLE 3-9
FIELD TRUCK EMISSIONS PRODUCTION AT NCE S-2

Group	Source	Emissions (grams)		
		CO	**HC**	**NOx**
Contractor	Cold Starts	116	47	33
	Hot Starts	75	14	22
	Running/Idle	1,121	475	708
	TOTAL	**1,312**	**536**	**763**
TxDOT	Cold Starts	534	64	43
	Hot Starts	369	49	38
	Running/Idle	3,656	309	110
	TOTAL	**4,559**	**422**	**191**
GRAND TOTAL		**5,871**	**958**	**954**

I-35W/I-30

Total field truck emissions for the I-35W/I-30 study site are shown in Table 3-10. The field truck emissions at this study site increased significantly compared to the two prior study sites. The increased emissions production from the contractors' field trucks at this site resulted from the introduction of gasoline-fueled trucks at the construction site. Although there were slightly more field trucks, over 50% of the trucks were gasoline fueled, resulting in higher aggregate emissions rates.

The number of TxDOT field trucks at this site was the same as at both NCE sites; however, 80% of the vehicles at the site used gasoline rather than clean or dual fuel. No significant change is seen in the tables due to the assumption of combining the clean- or dual-fueled trucks with gasoline trucks. The previous statement concerning overestimation of TxDOT field truck emissions continues to apply in this case, however the overestimation is not as significant as in the previous cases.

TABLE 3-10
FIELD TRUCK EMISSIONS PRODUCTION AT I-35W/I-30

Group	Source	Emissions (grams)		
		CO	**HC**	**NOx**
Contractor	Cold Starts	1,113	127	82
	Hot Starts	293	42	37
	Running/Idle	12,687	1,220	646
	TOTAL	**14,093**	**1,389**	**765**
TxDOT	Cold Starts	577	59	38
	Hot Starts	256	36	29
	Running/Idle	3,551	300	107
	TOTAL	**4,384**	**395**	**174**
GRAND TOTAL		**18,477**	**1,784**	**939**

I-820 NE

The I-820 NE study site produced slightly lower field truck emissions than those observed at the I-35W/I-30 study site. Total emissions produced by field trucks are shown in Table 3-11. The total emissions remain high relative to all study sites. This results from operating a number of gasoline-fueled field trucks. The decease from the levels observed at the I-35W/I-30 study site also results from shorter running times observed on contractors' field trucks. Of the four large study sites observed, this site had the shortest total running times. The decease in running-time associated emissions was offset slightly by the hot start emissions. This site produced twice the number of hot starts than the other three large sites.

TxDOT field trucks generated the largest amount of emissions observed at any of the three large sites. The higher number of hot starts and running emissions contributed to this high emissions production.

TABLE 3-11
FIELD TRUCK EMISSIONS PRODUCTION AT I-820 NE

Group	Source	Emissions (grams)		
		CO	**HC**	**NOx**
Contractor	Cold Starts	1,035	108	69
	Hot Starts	648	92	73
	Running/Idle	9,974	895	393
	TOTAL	**11,657**	**1,095**	**535**
TxDOT	Cold Starts	701	72	46
	Hot Starts	426	60	48
	Running/Idle	4,189	355	127
	TOTAL	**5,316**	**487**	**221**
GRAND TOTAL		**16,973**	**1,582**	**756**

FM 156

The emissions produced by the contractor's field truck at this site are less than half of the emissions observed at larger sites such as those on NCE. In some cases, the emissions are 4% of the highest observed site (I-35W/I-30). Table 3-12 shows the total field truck emissions for the FM 156 study site.

No comparison to TxDOT vehicles is made because this data was not obtained. To determine the site's total emissions production, the team used similar activity values based on visual accounts of TxDOT and contractor's field trucks at the site.

TABLE 3-12
FIELD TRUCK EMISSIONS PRODUCTION AT FM 156

Group	Source	Emissions (grams)		
		CO	HC	NOx
Contractor	Cold Starts	206	21	13
	Hot Starts	36	5	4
	Running/Idle	276	23	8
	TOTAL	**518**	**49**	**25**
TxDOT	Cold Starts [1]	206	21	13
	Hot Starts [1]	36	5	4
	Running/Idle [1]	276	23	8
	TOTAL [1]	**518**	**49**	**25**
GRAND TOTAL		**1,036**	**98**	**50**

[1] Activity values were input from data collected from the contractor at the same site.

Summary

The summary of field truck emissions, shown in Table 3-13, allows for comparisons between sites and groups. As stated in previous discussions of each site, the team observed the highest emissions from contractor's field trucks at the I-35W/I-30 study site. This resulted from a larger number of trucks used, the most number of hot starts observed, and the longest total running times observed. The team observed the highest emissions from TxDOT field trucks at the I-820 NE study site. This resulted from a large number of trucks relative to other sites, the most number of hot starts observed, and the longest running times observed. The total of all study sites yielded 48 kg of CO, 5 kg of HC, and 4 kg of NOx. These totals are small and insignificant compared to the hundreds or thousands of tons of pollutants inventoried in nonattainment areas.

TABLE 3-13
SUMMARY OF FIELD TRUCK EMISSIONS PRODUCTION

Site	Group	Emissions (grams)		
		CO	HC	NOx
NCE S-1	Contractor	1,260	512	713
	TxDOT	4,585	423	190
	TOTAL	**5,845**	**935**	**903**
NCE S-2	Contractor	1,312	536	763
	TxDOT	4,559	422	191
	TOTAL	**5,871**	**958**	**954**
I-35W/I-30	Contractor	14,093	1,389	765
	TxDOT	4,384	395	174
	TOTAL	**18,477**	**1,784**	**939**
I-820 NE	Contractor	11,657	1,095	535
	TxDOT	5,316	487	221
	TOTAL	**16,973**	**1,582**	**756**
FM 156	Contractor	518	49	25
	TxDOT	518	49	25
	TOTAL	**1,036**	**98**	**50**
GRAND TOTAL		**48,202**	**5,357**	**3,602**

MATERIALS TRUCKS

The research team observed trucks delivering and removing materials from the construction sites. The nine observed activities at the sites ranged from the delivery of concrete, asphalt, and lime to the removal of excavated material and asphalt demolition. Table 3-14 shows the activities of the materials trucks by site. This table also shows the recorded number of trucks and their observed on-site activity characteristics. On-site duration is defined as the amount of time when a materials truck first came into view at the site until it left that location. In some cases, the materials trucks may have been physically on the construction site longer than recorded by the observation team.

TABLE 3-14
MATERIALS TRUCKS ACTIVITY CHARACTERISTICS BY STUDY SITE

Site	Activity	Trucks Observed	On-Site Duration (hours)				
			Total	Average	Std. Dev.	Min	Max
NCE S-1	Remove Spoils	114	12.45	0.11	0.05	0.03	0.28
	Deliver/Place Lime	16	3.44	0.22	0.05	0.13	0.32
	Deliver Fill	18	2.51	0.14	0.08	0.02	0.28
	Deliver Concrete [1]	n/a	n/a	n/a	n/a	n/a	n/a
NCE S-2	Deliver Concrete [2]	18	3.08	0.17	0.00	0.02	0.33
	Remove Spoils	15	0.73	0.03	0.00	0.02	0.17
I-35W/I-30	Deliver Concrete	27	15.77	0.58	0.13	0.38	0.88
I-820 NE	Deliver Fill	8	2.02	0.25	0.12	0.08	0.43
	Remove Spoils	26	4.53	0.17	0.14	0.10	0.80
FM 156	Deliver Asphalt	57	12.23	0.20	0.01	0.07	0.65

[1] Data not collected
[2] Partial data

The observation team was unable to collect materials truck information for two activities noted in the previous table. The concrete delivery activity observed at NCE S-1 at Hall Street was noted but was out of sight for the observation team to collect any reasonable data. The concrete delivery activity the team observed on the NCE S-2 study site at University Boulevard only represents partial data from this activity. The observation team began recording activity information at this location after the work commenced and materials trucks had cycled for some unknown time. This omission results in an underestimation of the materials trucks emissions from these two study sites. Both of these activities were of a short duration and the team cannot approximate the exact duration of the activity observed at the I-35W/I-30 study site. Because of this, the research team only used partial data collected from the NCE S-2 study site at University Boulevard for further computation on the site's total emissions production.

Of the nine activities observed, only a third had total on-site durations greater than 12 hours. The majority of activities recorded had on-site duration between 2 and 4 hours. Most of the activities are characterized as short duration events.

The average on-site time for materials trucks ranged from 0.03 hours to 0.58 hours. The team recorded the highest value during the placement of concrete on an elevated section. Trucks were queued prior to delivery of their load at the concrete pump and then drivers cleaned their trucks on-site, away from the activity, prior to returning to the concrete batch plant. On-site times for similar activities the team observed at other sites were lower because the trucks left the activity location prior to cleaning activities. If the cleaning activities were recorded, then these on-site times would be higher.

Typically, the on-site times averaged 0.20 hours or 12 minutes. This is a short headway between trucks. The observation teams did not record any significant delay times at the sites that would indicate inefficient cycling or rotating of materials trucks.

Emissions

The emissions estimates were calculated as the product of the total on-site time and the idling emissions rate for heavy-duty diesel vehicles (HDDV). Table 3-15 shows the emissions production estimates from the five study sites. The highest emissions producing sites were NCE S-1, I-35W/I-30, and FM 156, in decreasing order. It is interesting to note that the latter two sites only recorded one activity each and had similar results to the combined three activities observed at the NCE S-1 study site. This observation shows that the activity at I-35W/I-30 and FM 156 was either more intense in nature or required the trucks to be on-site longer. The latter observation is most likely the cause of the high emissions production as Table 3-14 shows that the average on-site times were higher and the activities lasted longer.

An overall review of the emissions show that these totals are lower than the totals observed from the field trucks. The contribution of materials trucks emissions to the total site's emissions is expected to be small to insignificant. The emissions analysis used here only provides a rough estimate.

The effects of materials trucks in transit to and from the construction site are not included in this analysis. Additional emissions from materials trucks would be sourced through vehicle-miles traveled at average speeds, and idling emissions at a location away from the construction site (batch plant, etc.). Therefore, the results from this emissions section are underestimated.

TABLE 3-15
EMISSIONS PRODUCTION FROM MATERIALS TRUCKS ACTIVITIES

Site	Activity	Emissions (kg)		
		CO	HC	NOx
NCE S-1	Remove Spoils	1.1	0.2	0.6
	Deliver/Place Lime	0.3	0.0	0.2
	Deliver Fill	0.3	0.0	0.1
	Deliver Concrete [1]	n/a	n/a	n/a
	TOTAL	**1.7**	**0.2**	**0.9**
NCE S-2	Deliver Concrete [2]	0.3	0.0	0.2
	Remove Spoils	0.1	0.0	0.0
	TOTAL	**0.3**	**0.0**	**0.2**
I-35W/I-30	Deliver Concrete	1.4	0.2	0.8
	TOTAL	**1.4**	**0.2**	**0.8**
I-820 NE	Deliver Fill	0.2	0.0	0.1
	Remove Spoils	0.4	0.1	0.2
	TOTAL	**0.6**	**0.1**	**0.3**
FM 156	Deliver Asphalt	1.1	0.1	0.6
	TOTAL	**1.1**	**0.1**	**0.6**
GRAND TOTAL		**5.1**	**0.6**	**2.8**

[1] Data not collected
[2] Partial data

CONSTRUCTION EQUIPMENT

Activity

Table 3-16 shows the distribution of equipment engine hours of use by fuel type. Gasoline-fueled equipment use hours ranged from 10% to 65% of the diesel-fueled equipment use hours. This proportion decreases as the use hours of diesel equipment increases. The location with the highest observed gasoline-fueled engine use hours was the I-35W/I-30 study site. This resulted from the high use of light-duty equipment such as small portable generators and portable light plants used for the pre-dawn placement of concrete. The team did not observe any gasoline-fueled equipment being used at the FM 156 study site.

Figures 3-9 and 3-10 graphically show the information from Table 3-16. As seen in the table and these figures, the majority of equipment used is diesel fueled. The remainder of the equipment used at the study sites is light-duty, gasoline-fueled equipment. This equipment is classified, according to AP-42, in the Misc class, and represents small portable gasoline-fueled equipment such as generators < 50 Hp, compressors, and light plants as well as other light-duty equipment.

TABLE 3-16
CONSTRUCTION ENGINE HOURS OF USE BY AP-42 CLASS AND FUEL SOURCE

Fuel Source	**AP-42 Equipment Class**	**Engine Hours of Use Observed by Site**				
		NCE S-1	**NCE S-2**	**I-35W/I-30**	**I-820 NE**	**FM 156**
Diesel	Track-Type Tractor	16.52	7.32	0.98	6.73	0
	Wheeled Tractor	0	0	0	0	0
	Wheeled Dozer	0	0	0	0	0
	Scraper	0	0	0	0	0
	Motor Grader	19.18	0.05	6.21	7.14	0
	Wheeled Loader	40.51	25.10	9.67	19.78	2.42
	Track-Type Loader	0	0	0	5.8	0
	Off-Highway Truck	7.73	4	8.59	7.53	11.45
	Roller	26.57	0.00	5.8	6.99	34.21
	Misc	41.3	22.75	13.24	8.09	12.52
	TOTAL	**151.81**	**59.19**	**44.49**	**62.06**	**60.60**
Gasoline	Track-Type Tractor	0	0	0	0	0
	Wheeled Tractor	0	0	0	0	0
	Wheeled Dozer	0	0	0	0	0
	Scraper	0	0	0	0	0
	Motor Grader	0	0	0	0	0
	Wheeled Loader	0	0	0	0	0
	Track-Type Loader	0	0	0	0	0
	Off-Highway Truck	0	0	0	0	0
	Roller	0	0	0	0	0
	Misc	13.53	19.37	28.87	20.72	0
	TOTAL	**13.53**	**19.37**	**28.87**	**20.72**	**0.00**
GRAND TOTAL		**165.34**	**78.56**	**73.36**	**82.78**	**60.6**

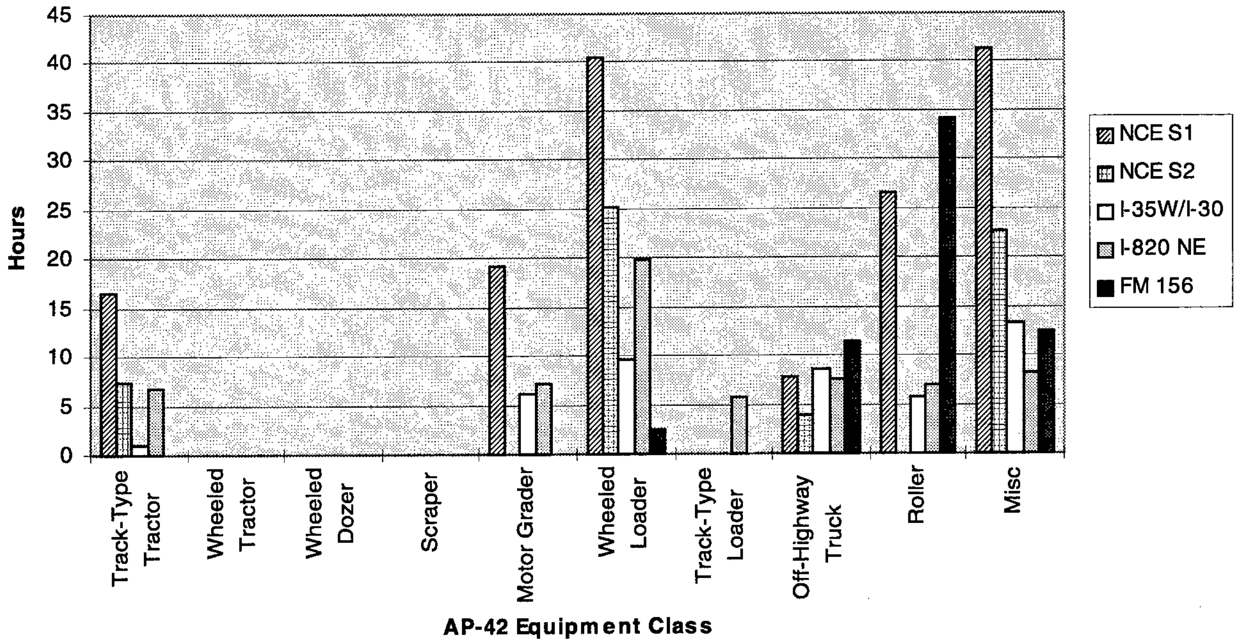


FIGURE 3-9. Hours of Use Observed for Diesel-Fueled Equipment

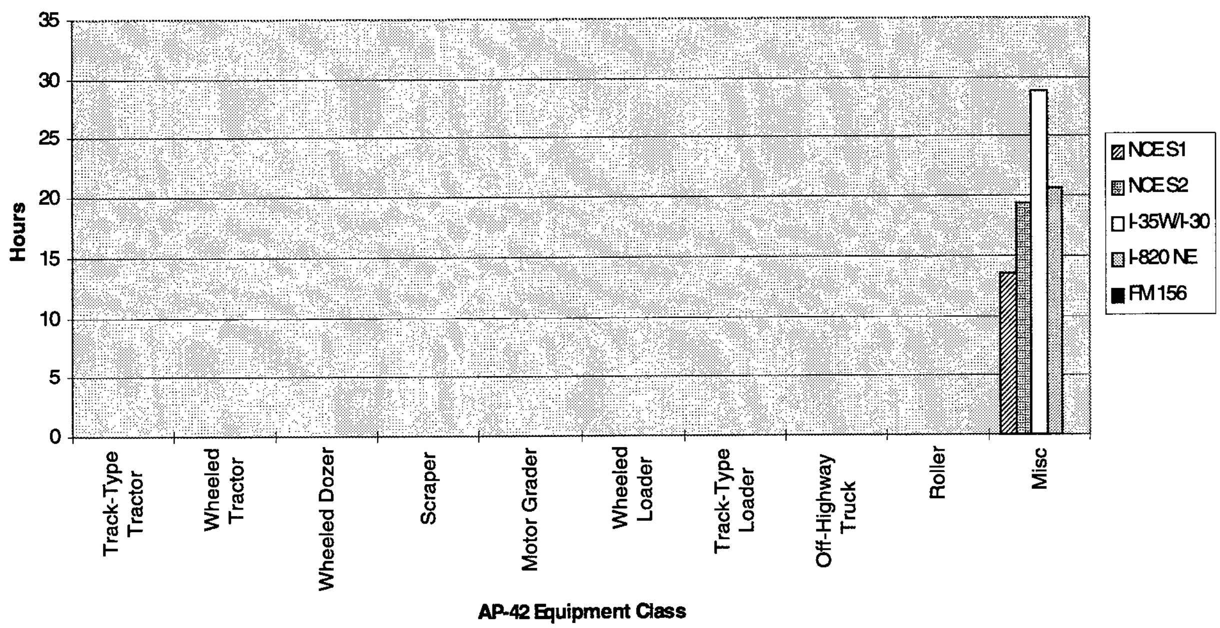


FIGURE 3-10. Hours of Use Observed for Gasoline-Fueled Equipment

Emissions

The team made three observations after data collection and during the preparation of this report. These observations focused on equipment types in some of the AP-42 equipment classes.

First, the Wheeled Loader class includes a variety of equipment sizes. These different sizes of equipment should have different emissions rates. The smaller loaders observed at the study sites should have lower emissions rates than larger loaders. Therefore, the team may have made some overestimation of equipment emissions.

Second, the Off-highway Truck class may not correctly represent the types of vehicles observed at the study sites. Most of the vehicles at the study sites grouped into this class were larger heavy-duty, diesel vehicles which have lower emissions rates than those provided in AP-42 for the Off-highway Truck class. Therefore, the team may have made some overestimation of equipment emissions.

Finally, the Misc class contained the highest variation of equipment of any of the AP-42 classes. It encompassed cranes and small portable generators. Clearly, the emissions rates from these types of equipment are different. Cranes are expected to have higher emissions rates than small portable cranes. Because of the number of smaller pieces of equipment, the team may have made some overestimation of equipment emissions.

Table 3-17 summarizes the construction equipment emissions by fuel source against the three primary pollutants (CO, exhaust HC, and NOx) and three other pollutants and two additional HC categories. The additional HC categories (evaporative and crankcase) do not significantly add to the totals obtained from exhaust HC. The total from aldehydes (R-C(OH)) also is insignificant when compared to the three primary pollutants. Emissions from sulphur oxides and PM are near 50% of the total exhaust HC. These three pollutants show no significant or any contribution from gasoline-powered equipment. PM matter emissions are supplemented, but not included in the analysis of this report, by the production of fugitive dust from wheel-pavement and wheel-earth interactions. In addition, construction sites typically have exposed soil, resulting in wind erosion that contributes to a construction site's total particulate emissions.

Tables 3-18 through 3-20 detail emissions for each study site by AP-42 equipment class and fuel source for CO, exhaust HC, and NOx respectively. The team calculated emissions as the product of engine hours of use and the respective AP-42 emissions rate. No consideration was given to the available horsepower or power loading of construction equipment. Although these variables will yield a more accurate estimate of emissions, the method used assumes the engine is under a full load and therefore produces the highest emissions. This assumption results in an overestimate of emissions from construction equipment.

TABLE 3-17

CONSTRUCTION EQUIPMENT EMISSIONS BY FUEL SOURCE

Pollutant	Fuel Source	Emissions (kg)					
		NCE S-1	NCE S-2	I-35W/I-30	I-820 NE	FM 156	TOTAL
CO	Diesel	37	18	15	17	19	106
	Gasoline	104	150	223	160	0	637
	TOTAL	**141**	**168**	**238**	**177**	**19**	**743**
Exhaust HC	Diesel	10	5	3	4	3	25
	Gasoline	3	5	7	5	0	20
	TOTAL	**13**	**10**	**10**	**9**	**3**	**45**
Evaporative HC	Diesel	--	--	--	--	--	--
	Gasoline	0	0	1	1	0	2
	TOTAL	**0**	**0**	**1**	**1**	**0**	**2**
Crankcase HC	Diesel	--	--	--	--	--	--
	Gasoline	1	1	1	1	0	4
	TOTAL	**1**	**1**	**1**	**1**	**0**	**4**
NOx	Diesel	107	51	40	48	47	293
	Gasoline	3	4	5	4	0	16
	TOTAL	**111**	**56**	**46**	**53**	**47**	**313**
Aldehydes	Diesel	2	1	1	1	1	6
	Gasoline	0	0	0	0	0	0
	TOTAL	**2**	**1**	**1**	**1**	**1**	**6**
Sulphur Oxides	Diesel	10	5	4	5	4	28
	Gasoline	0	0	0	0	0	0
	TOTAL	**10**	**5**	**4**	**5**	**4**	**28**
Particulate Matter	Diesel	9	4	3	4	3	23
	Gasoline	0	0	0	0	0	0
	TOTAL	**9**	**4**	**3**	**4**	**3**	**23**

These tables show that construction equipment produces CO in greatest quantities, followed by NOx and HC respectively. The team observed the highest CO production at the I-35W/I-30 study site. This resulted from the use of a large number of gasoline-fueled, light duty pieces of equipment falling into the Misc class. The FM 156 study site produced the second highest total from the use of equipment in the Rollers and Off-highway Truck classes.

Surprisingly, both of the NCE study sites produced fewer CO emissions with the NCE S-1 study site having the least CO emissions. Although these sites had more (NCE S-1 significantly more) emissions from diesel equipment, the gasoline-fueled equipment use at the two other large sites exceeded the NCE study sites totals. The NCE S-1 study site had the highest emissions from the diesel Misc class resulting from the use of the cranes and other equipment. Throughout this discussion, one observation stands out—the contribution of gasoline-fueled equipment to CO emissions is greater than the contribution from diesel-fueled equipment.

TABLE 3-18
CO EMISSIONS FROM CONSTRUCTION EQUIPMENT BY STUDY SITE

Fuel Source	AP-42 Equipment Class	CO (kg)					
		NCE S-1	NCE S-2	I-35W/I-30	I-820 NE	FM 156	TOTAL
Diesel	Track-Type Tractor	2.6	1.1	0.2	1.0	0.0	4.9
	Wheeled Tractor	0.0	0.0	0.0	0.0	0.0	0.0
	Wheeled Dozer						
	Scraper	0.0	0.0	0.0	0.0	0.0	0.0
	Motor Grader	1.3	0.0	0.4	0.5	0.0	2.2
	Wheeled Loader	10.5	6.5	2.5	5.1	0.6	25.2
	Track-Type Loader	0.0	0.0	0.0	0.5	0.0	0.5
	Off-Highway Truck	6.3	3.2	7.0	6.2	9.4	32.1
	Roller	3.7	0.0	0.8	1.0	4.7	10.2
	Misc	12.6	7.0	4.0	2.5	3.8	29.9
	TOTAL	**37.0**	**17.8**	**14.9**	**16.8**	**18.5**	**105.0**
Gasoline	Track-Type Tractor						
	Wheeled Tractor	0.0	0.0	0.0	0.0	0.0	0.0
	Wheeled Dozer						
	Scraper						
	Motor Grader	0.0	0.0	0.0	0.0	0.0	0.0
	Wheeled Loader	0.0	0.0	0.0	0.0	0.0	0.0
	Track-Type Loader						
	Off-Highway Truck						
	Roller	0.0	0.0	0.0	0.0	0.0	0.0
	Misc	104.4	149.5	222.9	160.0	0.0	636.8
	TOTAL	**104.4**	**149.5**	**222.9**	**160.0**	**0.0**	**636.8**
GRAND TOTAL		**141.4**	**167.3**	**237.8**	**176.8**	**18.5**	**741.8**

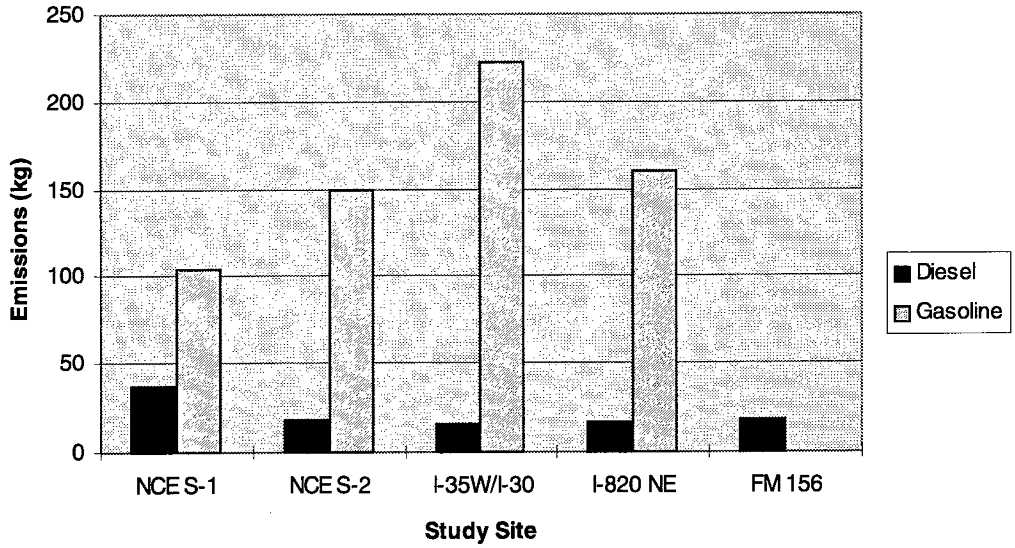


FIGURE 3-11. Construction Equipment Emissions - CO

The HC emissions from all sites are relatively insignificant to the other two primary pollutants; the totals range from 3 kg to 13 kg of exhaust HC as shown in Table 3-19. The sites producing the highest exhaust HC emissions are the NCE S-1 and I-35W/I-30 study sites, respectively. The next highest producing sites are the NCE S-2 and I-820 NE study sites, followed by the FM 156 study site at one-third the total production of these sites. Diesel-fueled equipment contributed the most to HC production at the NCE S-1 study site. This resulted from the use of equipment classified in Wheeled Loaders and Misc classes. Gasoline-fueled equipment contributed to equal or greater amounts of HC emissions at the NCE S-2, I-35W/I-30, and I-820 NE study sites. This was due to the use of light duty, gasoline-fueled equipment that is characterized by higher emissions rates.

TABLE 3-19
EXHAUST HC EMISSIONS FROM CONSTRUCTION EQUIPMENT BY STUDY SITE

Fuel Source	AP-42 Equipment Class	Exhaust HC (kg)					
		NCE S-1	NCE S-2	I-35W/I-30	I-820 NE	FM 156	TOTAL
Diesel	Track-Type Tractor	0.9	0.4	0.0	0.4	0.0	1.7
	Wheeled Tractor	0.0	0.0	0.0	0.0	0.0	0.0
	Wheeled Dozer						
	Scraper	0.0	0.0	0.0	0.0	0.0	0.0
	Motor Grader	0.3	0.0	0.1	0.1	0.0	0.5
	Wheeled Loader	4.6	2.8	1.1	2.2	0.3	11.0
	Track-Type Loader	0.0	0.0	0.0	0.2	0.0	0.2
	Off-Highway Truck	0.7	0.3	0.7	0.6	1.0	3.3
	Roller	0.8	0.0	0.2	0.2	1.0	2.2
	Misc	2.4	1.4	0.8	0.5	0.7	5.8
	TOTAL	**9.7**	**4.9**	**2.9**	**4.2**	**3.0**	**24.7**
Gasoline	Track-Type Tractor						
	Wheeled Tractor	0.0	0.0	0.0	0.0	0.0	0.0
	Wheeled Dozer						
	Scraper						
	Motor Grader	0.0	0.0	0.0	0.0	0.0	0.0
	Wheeled Loader	0.0	0.0	0.0	0.0	0.0	0.0
	Track-Type Loader						
	Off-Highway Truck						
	Roller	0.0	0.0	0.0	0.0	0.0	0.0
	Misc	3.4	4.9	7.3	5.3	0.0	20.9
	TOTAL	**3.4**	**4.9**	**7.3**	**5.3**	**0.0**	**20.9**
GRAND TOTAL		**13.1**	**9.8**	**10.2**	**9.5**	**3.0**	**45.6**

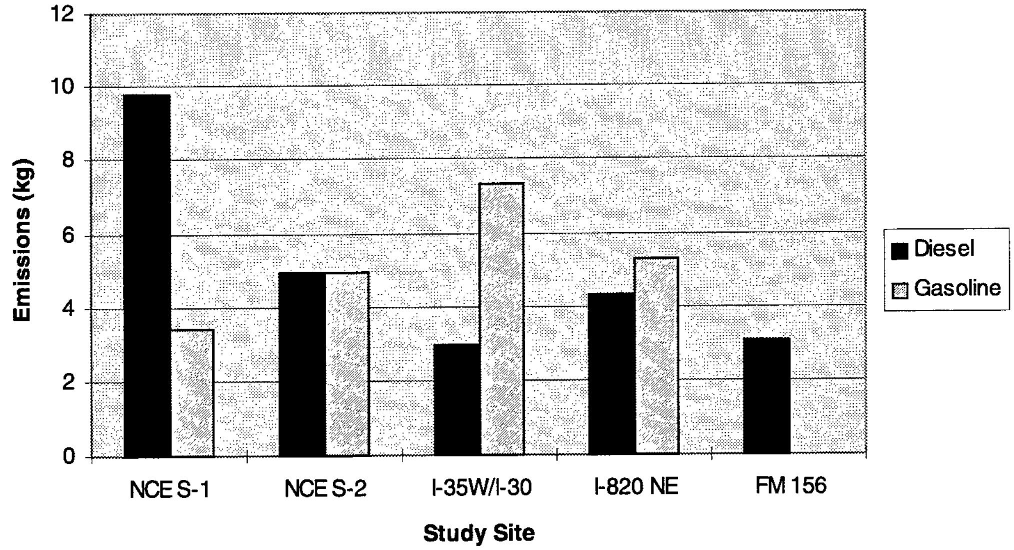


FIGURE 3-12. Construction Equipment Emissions - Exhaust HC

The results from the NOx emissions analysis, Table 3-20, show that the NCE S-1 study site produced the highest amount of emissions followed by the NCE S-2, I-820 NE, I-35W/I-30 and FM 156 study sites, respectively in decreasing order. The NCE S-1 site NOx production results from the limited use of gasoline-fueled equipment and the more predominant use of diesel-fueled equipment. The diesel equipment used has higher NOx emissions rates than its gasoline counterpart. The high level of equipment activity in the following classes added to the high NOx production: Track-Type Loaders, Wheeled Loaders, Rollers, and Misc. Equipment in the majority of these classes is used during earthwork activities. The NOx production at the NCE S-2 and I-820 NE study sites is comparable. The two sites balanced each other in the equipment classes. For example, the sites had comparable totals from diesel-fueled Track-Type Tractors and gasoline-fueled Misc equipment. The NCE S-2 study site had higher totals in the diesel-fueled Wheeled Loader and Misc classes. The I-820 NE study site had higher totals in Motor Grader, Off-Highway Truck, and Roller classes. The research team noted that the FM 156 study site produced NOx emissions from diesel-fueled equipment that was comparable to the I-280 NE study site.

TABLE 3-20
NOx EMISSIONS FROM CONSTRUCTION EQUIPMENT BY STUDY SITE

Fuel Source	AP-42 Equipment Class	NOx (kg)					
		NCE S-1	NCE S-2	I-35W/I-30	I-820 NE	FM 156	TOTAL
Diesel	Track-Type Tractor	9.4	4.2	0.6	3.8	0.0	18.0
	Wheeled Tractor	0.0	0.0	0.0	0.0	0.0	0.0
	Wheeled Dozer						
	Scraper	0.0	0.0	0.0	0.0	0.0	0.0
	Motor Grader	6.2	0.0	2.0	2.3	0.0	10.5
	Wheeled Loader	34.8	21.5	8.3	17.0	2.1	83.7
	Track-Type Loader	0.0	0.0	0.0	2.2	0.0	2.2
	Off-Highway Truck	14.6	7.5	16.2	14.2	21.6	74.1
	Roller	10.4	0.0	2.3	2.7	13.4	28.8
	Misc	31.7	17.5	10.2	6.2	9.6	75.2
	TOTAL	**107.1**	**50.7**	**39.6**	**48.4**	**46.7**	**292.5**
Gasoline	Track-Type Tractor						
	Wheeled Tractor	0.0	0.0	0.0	0.0	0.0	0.0
	Wheeled Dozer						
	Scraper						
	Motor Grader	0.0	0.0	0.0	0.0	0.0	0.0
	Wheeled Loader	0.0	0.0	0.0	0.0	0.0	0.0
	Track-Type Loader						
	Off-Highway Truck						
	Roller	0.0	0.0	0.0	0.0	0.0	0.0
	Misc	2.5	3.6	5.4	3.9	0.0	15.4
	TOTAL	**2.5**	**3.6**	**5.4**	**3.9**	**0.0**	**15.4**
GRAND TOTAL		**109.6**	**54.3**	**45.0**	**52.3**	**46.7**	**307.9**

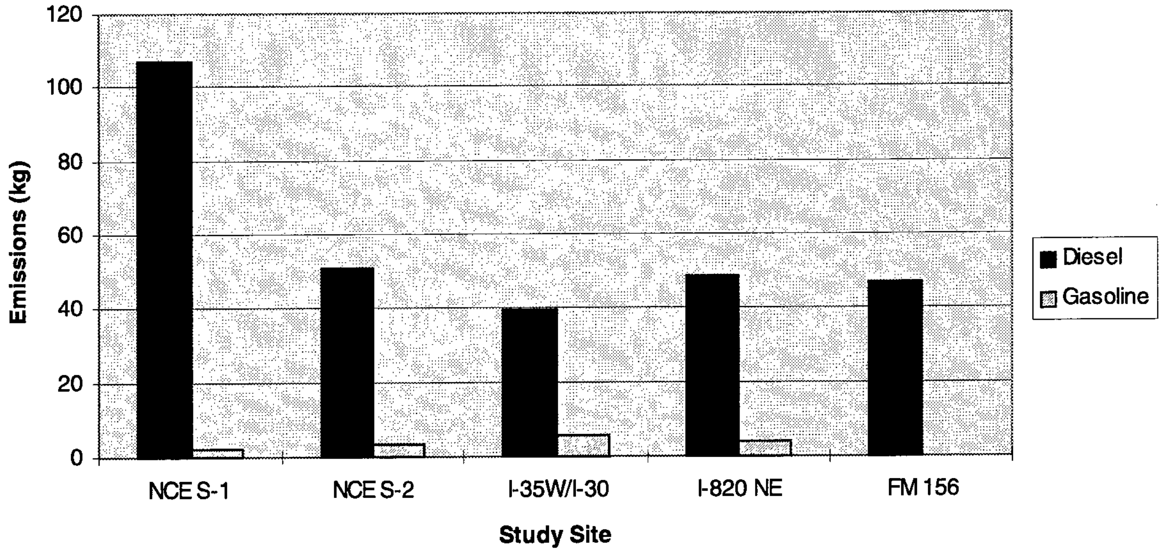


FIGURE 3-13. Construction Equipment Emissions - NOx

TOTAL EMISSIONS

The research team summed emissions from each vehicle category to generate estimates of the total emissions at each of the construction sites during the observation day. Table 3-21 shows this summary, and Figure 3-14 graphically presents the totals.

TABLE 3-21
SUMMARY OF HIGHWAY CONSTRUCTION CASE STUDY SITE EMISSIONS BY SITE AND SOURCE

Site	Source	Emissions (kg)			Emissions (tons)		
		CO	HC	NOx	CO	HC	NOx
NCE S-1	Field Trucks	5.846	0.936	0.904	0.006	0.001	0.001
	Materials Trucks	1.674	0.224	0.908	0.002	0.000	0.001
	Const. Equipment	141.507	13.212	109.678	0.156	0.015	0.121
	TOTAL	**149.027**	**14.372**	**111.490**	**0.164**	**0.016**	**0.123**
NCE S-2	Field Trucks	5.872	0.958	0.956	0.006	0.001	0.001
	Materials Trucks	0.347	0.046	0.188	0.000	0.000	0.000
	Const. Equipment	167.417	9.859	54.313	0.184	0.011	0.060
	TOTAL	**173.636**	**10.863**	**55.457**	**0.190**	**0.012**	**0.061**
I-35W/I-30	Field Trucks	18.477	1.785	0.939	0.020	0.002	0.001
	Materials Trucks	1.435	0.192	0.778	0.002	0.000	0.001
	Const. Equipment	237.839	10.303	44.937	0.262	0.011	0.049
	TOTAL	**257.751**	**12.280**	**46.654**	**0.284**	**0.013**	**0.051**
I-820 NE	Field Trucks	16.972	1.582	0.756	0.019	0.002	0.001
	Materials Trucks	0.596	0.080	0.323	0.001	0.000	0.000
	Const. Equipment	176.761	9.607	52.362	0.194	0.011	0.058
	TOTAL	**194.329**	**11.269**	**53.441**	**0.214**	**0.013**	**0.059**
FM !56	Field Trucks	1.037	0.099	0.052	0.001	0.000	0.000
	Materials Trucks	1.113	0.149	0.604	0.001	0.000	0.001
	Const. Equipment	18.536	3.057	46.765	0.020	0.003	0.051
	TOTAL	**20.686**	**3.305**	**47.421**	**0.022**	**0.003**	**0.000**
GRAND TOTAL		**795.429**	**52.089**	**314.463**	**0.874**	**0.057**	**0.294**

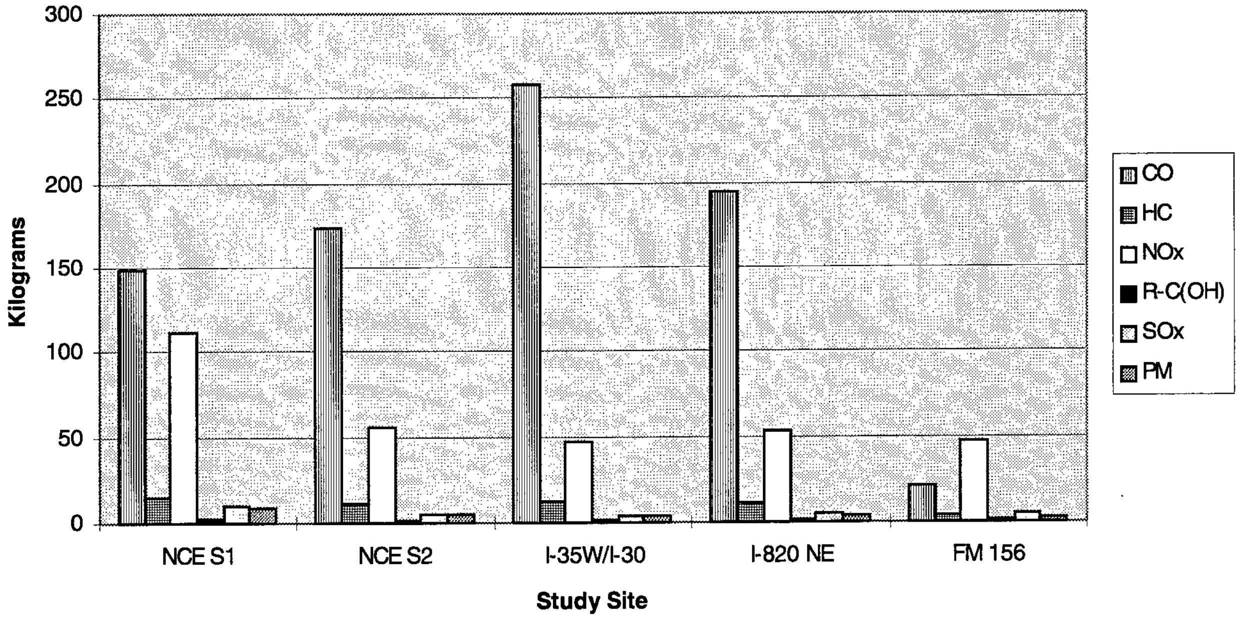


FIGURE 3-14. Summary of Highway Construction Case Study Site Emissions Production by Site and Source

The research team made four general observations when reviewing this data. First, as a site progresses from earthwork to more structural concrete or pavement work, NOx emissions will decrease as the CO emissions increase. There is not a correlation with HC emissions. Second, the only comparison made to gauge a project's emissions during phasing is at the NCE study sites. Here evidence shows that total emissions appear to increase as a site progresses though its construction schedule to some point at which activity begins to diminish and the total daily emissions diminish. Third, structural work appears to cause the highest emissions when major milestones are met, such as the placement of a large section of concrete. An increase in the use of equipment for one or more critical activities to help workers meet milestones may cause an increase in emissions. Finally, the total emissions for each of the three primary pollutants was less than one ton, which in terms of regional inventories, is a small amount. In fact, HC emissions from all five study sites totaled approximately 0.1 tons and NOx emissions totaled less than 0.3 tons.

To better understand how each source contributes to daily emissions production, Figures 3-15 though 3-19 graphically show each source's contributions to each study site's total emissions. The figures show that in each of the three primary pollutants, emissions from construction equipment represents 90% to 95% of CO emissions, 85% to 90% of HC emissions, and 95% to 99% of NOx emissions. Emissions from field trucks represents 5% to 10% of the CO production, 10% to 15% of HC emissions, and 1% to 2% of NOx emissions production. The emissions generated from materials trucks contributed 1% to CO and HC emissions at large construction sites, 5% to CO and HC emissions at small construction sites, and 1% of NOx emissions regardless of construction site size.

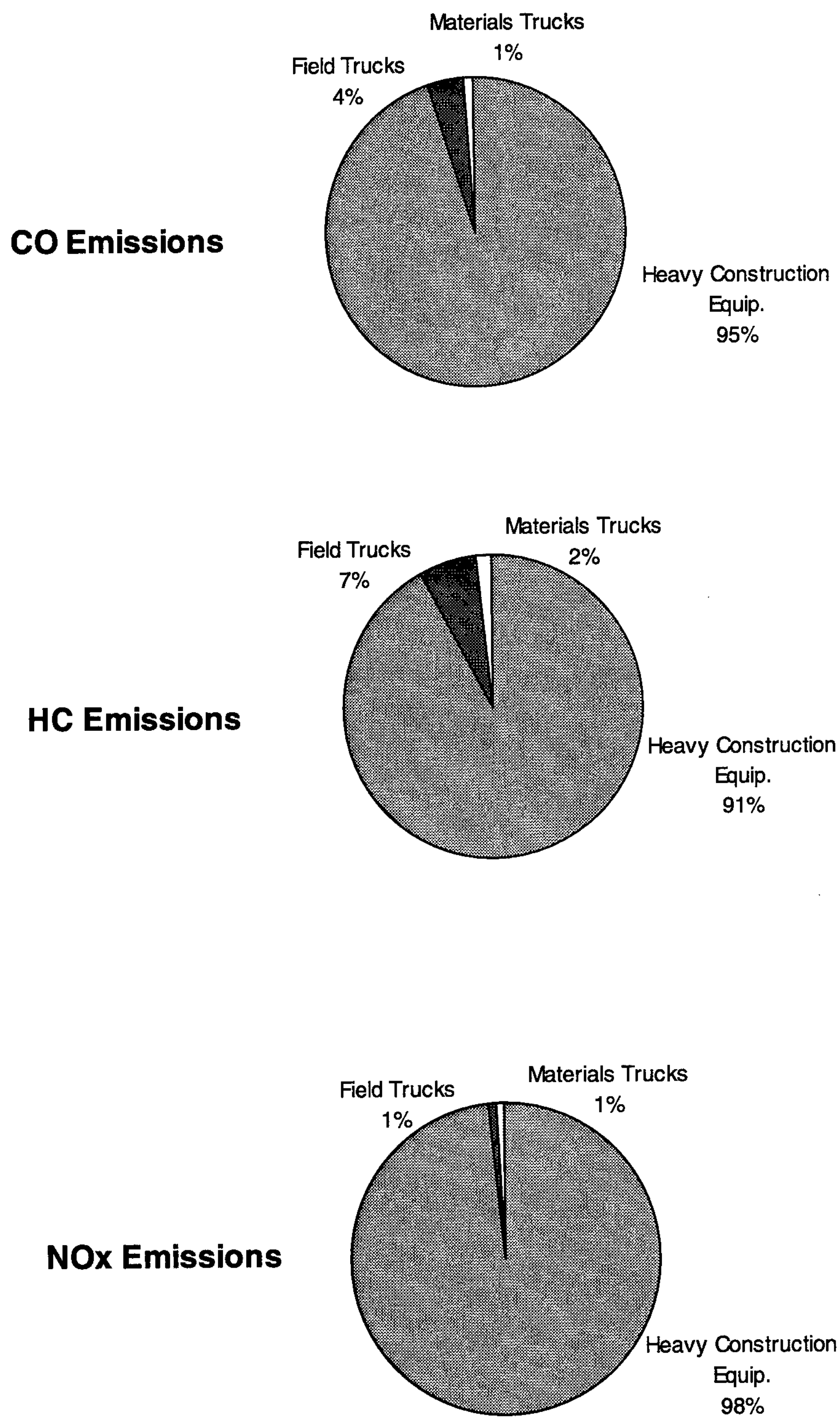


FIGURE 3-15. Construction Emissions Sources for CO, HC, and NOx at the NCE S-1 Study Site

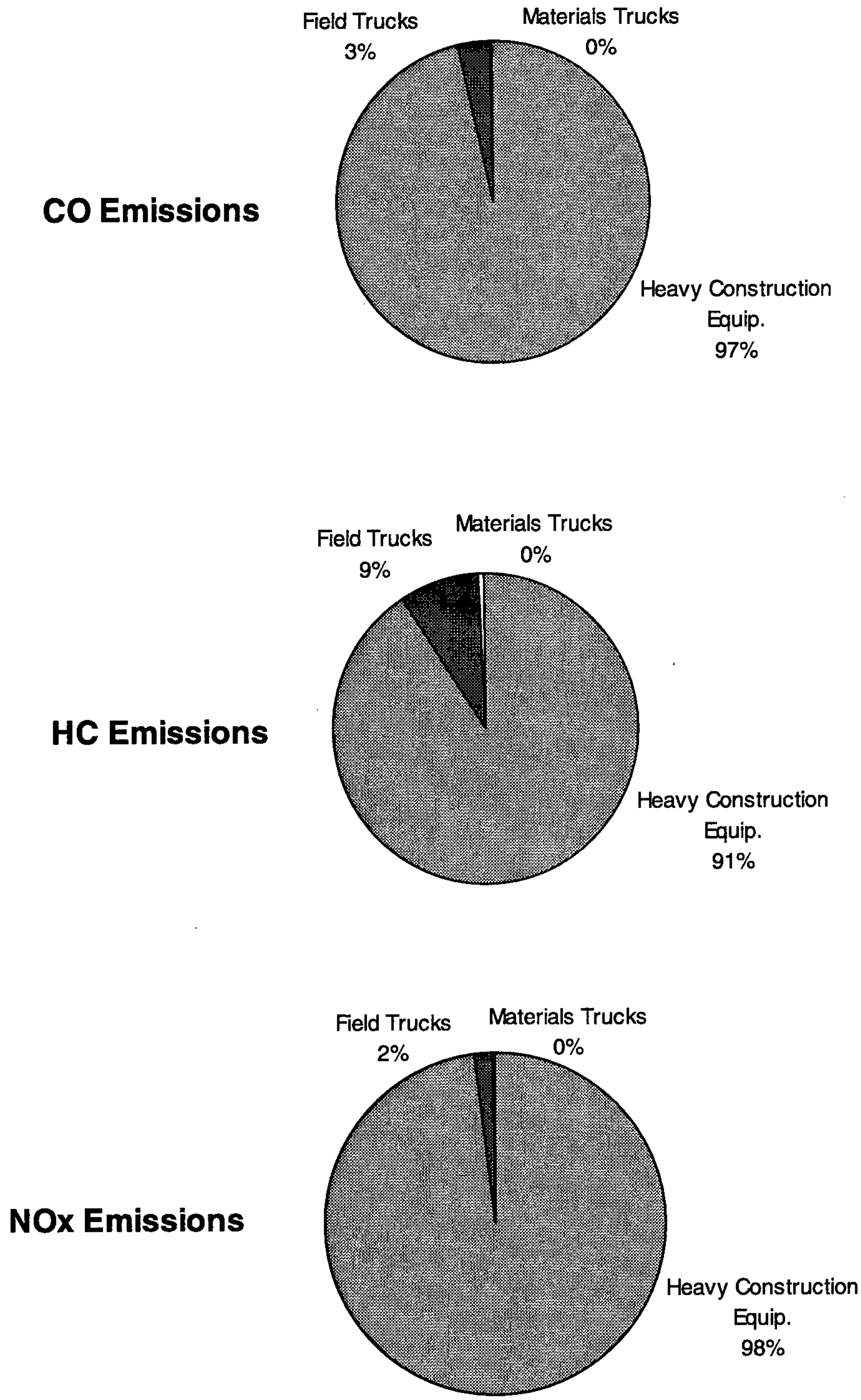


FIGURE 3-16. Construction Emissions Sources for CO, HC, and NOx at the NCE S-2 Study Site

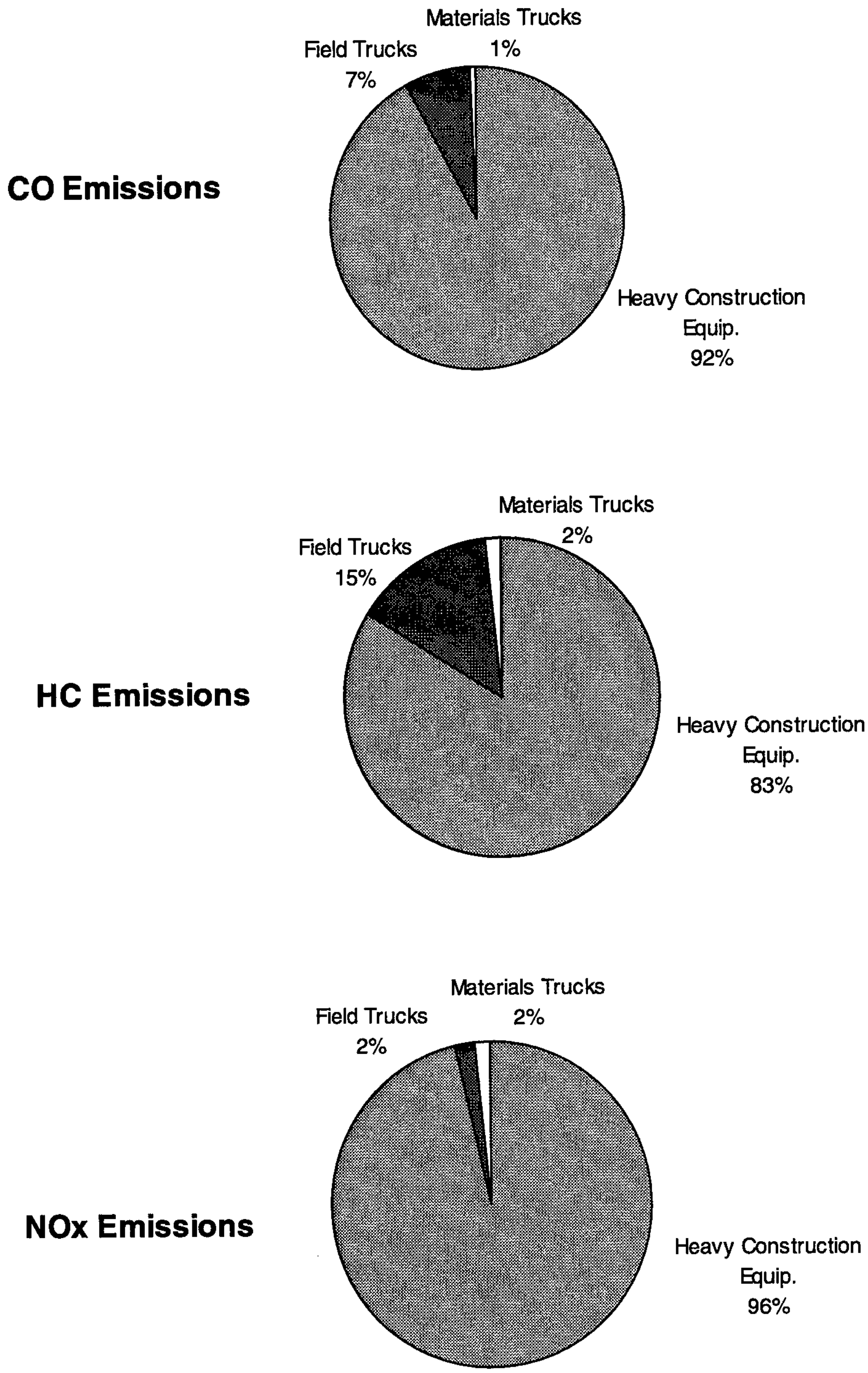


FIGURE 3-17. Construction Emissions Sources for CO, HC, and Nox at the I-35W/I-30 Study Site

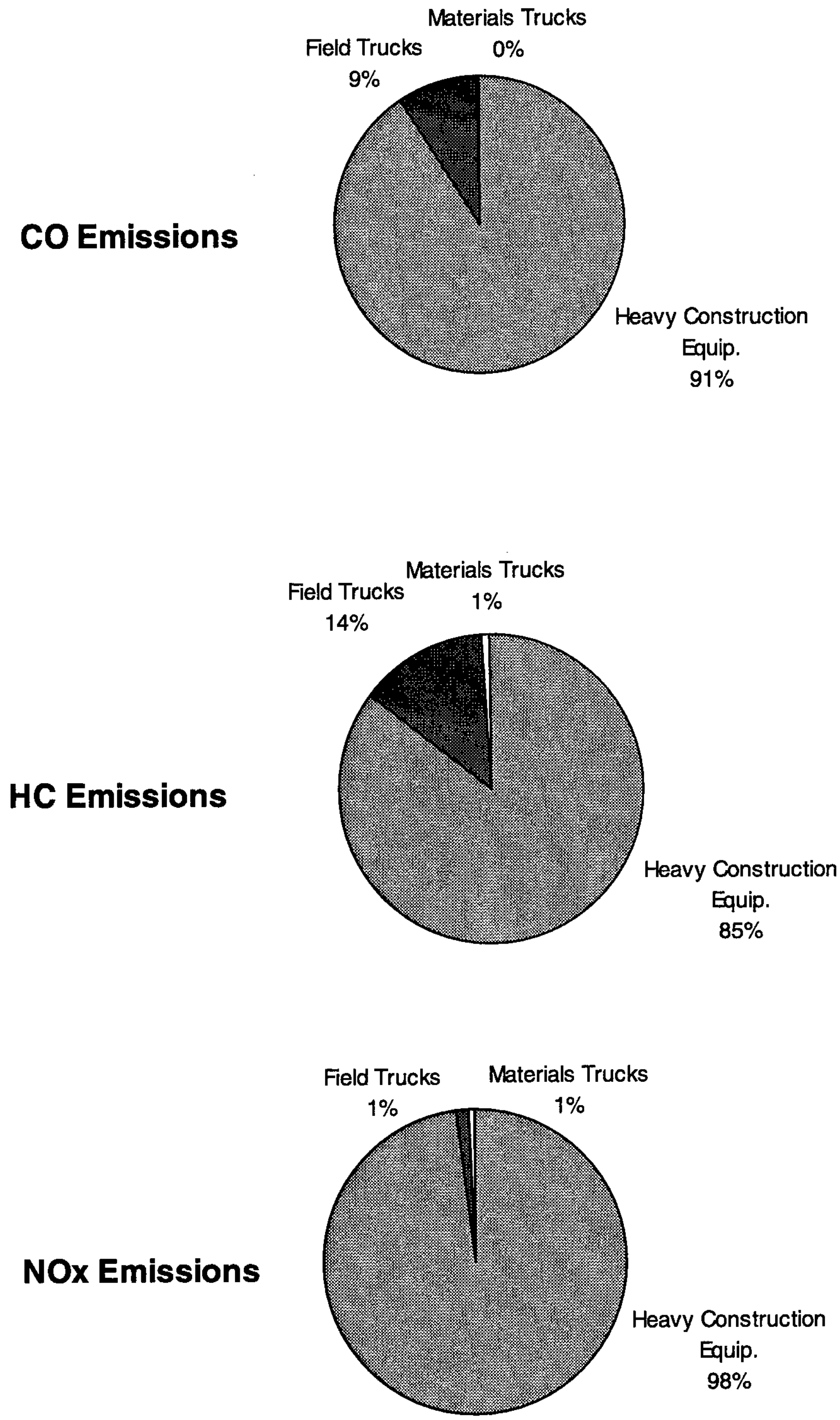


FIGURE 3-18. Construction Emissions Sources for CO, HC, and NOx at the I-820 NE Study Site

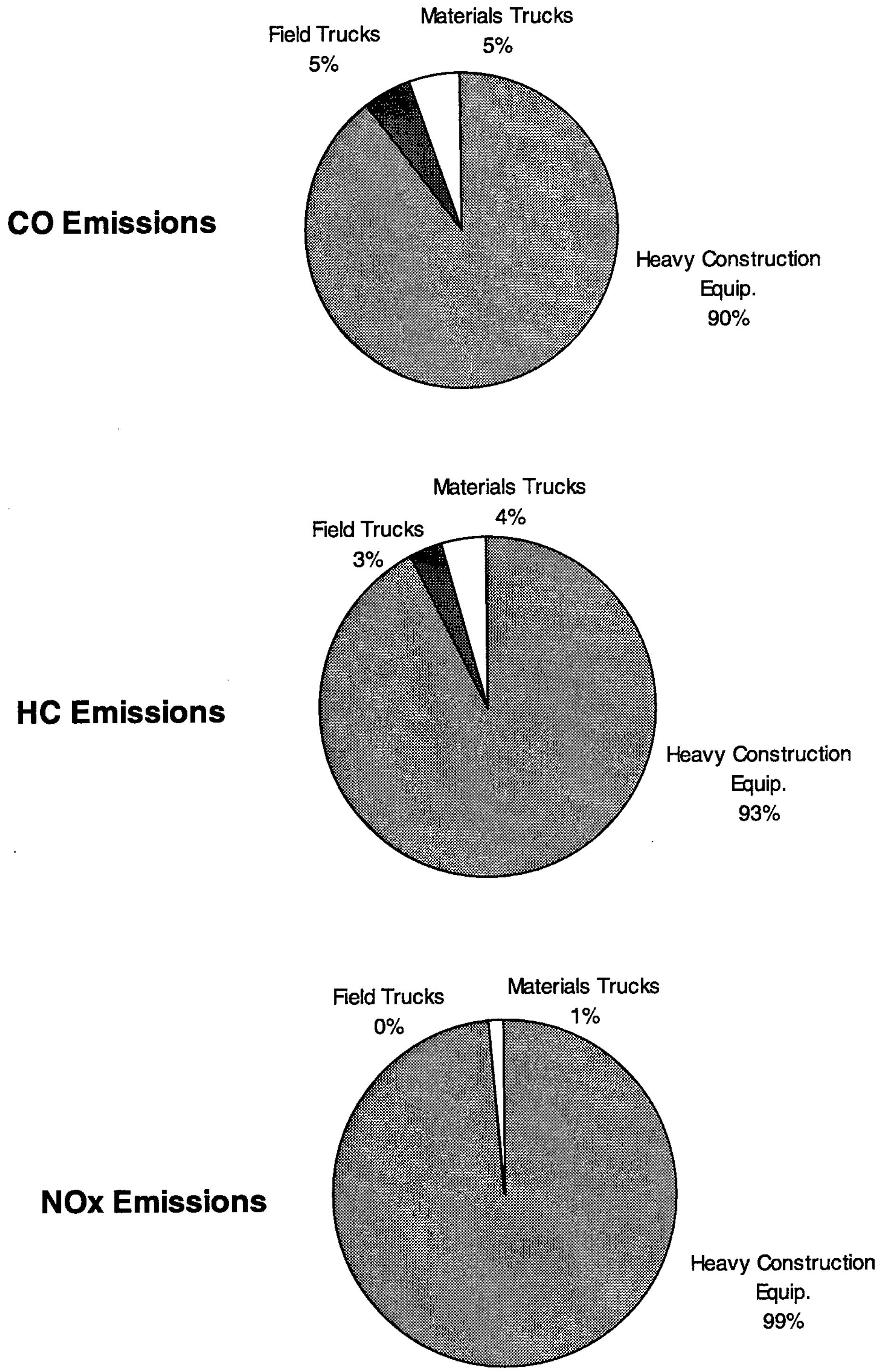


FIGURE 3-19. Construction Emissions Sources for CO, HC, and NOx at the FM 156 Study Site

EMISSIONS EQUIVALENCIES

The research team used emissions equivalencies to represent the equivalent VMT-related emissions production from specific vehicle types and the general fleet within the D/FW metropolitan region for each of the study sites. It is interesting to compare how emissions production at a particular site or the estimated emissions production from highway construction/maintenance projects are equated into VMT for typical passenger cars, and the general fleet. The vehicle types used in this analysis represent light duty gasoline vehicles (LDGV), light duty gasoline trucks < 6000 lbs. GVW (LDGT1), and light duty diesel vehicles (LDDV). These three types of vehicles most represent the specific types of typical vehicles on urban roadways. The research team obtained the general fleet distribution data from NCTCOG and it is the same distribution data used in their regional air quality analyses.

Table 3-22 shows these equivalencies for each of the five study sites. This table indicates that the four large construction sites produced CO VMT equivalencies in a range of 10,000 to 30,000, HC VMT emissions in a range of 5,000 to 10,000, and NOx VMT emissions in a range of 20,000 to 50,000. From the one small construction project, CO and HC VMT emissions equivalencies are near 2,000 VMT and are 20,000 VMT or less for NOx emissions.

The higher average speed (45 MPH) case resulted in higher VMT equivalencies for CO and HC emissions. However, there was no change for NOx emissions at four sites (NCE S-1, NCE S-2, I-820 NE, and FM 156) and a decrease at one site (I-35W/I-30). This decrease resulted from a rounding error. Closer inspection of NOx emissions at the I-35W/I-30 study site showed the values to be very similar, but when aggregated, were rounded in opposite directions.

The LDDV class consistently produces higher VMT equivalencies than the other two classes and the general fleet because the LDDV class produces higher CO emissions than the other classes used in this analysis. The VMT equivalencies increase from 15 MPH to 45 MPH for CO and HC emissions, but remain stable for NOx emissions.

Figures 3-20 and 3-21 graphically show the tabular information for the general vehicle fleet at 15 MPH and 45 MPH for each of the three primary pollutants.

TABLE 3-22
VMT EQUIVALENCIES OF STUDY SITE EMISSIONS

Site	Vehicle	VMT (000s) Equivalencies at 15 MPH			VMT (000s) Equivalencies at 45 MPH		
		CO	HC	NOx	CO	HC	NOx
NCE S-1	LDGV	8	6	77	20	13	72
	LDGT1	6	5	66	14	10	61
	LDDV	71	16	65	194	39	76
	General Fleet	6	5	46	16	10	46
NCE S-2	LDGV	9	5	38	24	10	36
	LDGT1	6	4	33	16	7	30
	LDDV	83	12	32	226	29	38
	General Fleet	7	4	23	18	8	23
I-35W/I-30	LDGV	14	5	32	36	11	30
	LDGT1	10	4	27	24	8	26
	LDDV	123	14	27	335	33	32
	General Fleet	11	4	20	27	9	19
I-820 NE	LDGV	10	5	37	27	10	35
	LDGT1	7	4	31	18	7	29
	LDDV	92	13	31	252	30	36
	General Fleet	8	4	22	20	8	22
FM 156	LDGV	1	1	33	3	3	31
	LDGT1	1	1	28	2	2	26
	LDDV	10	4	27	27	9	32
	General Fleet	1	1	20	2	2	20

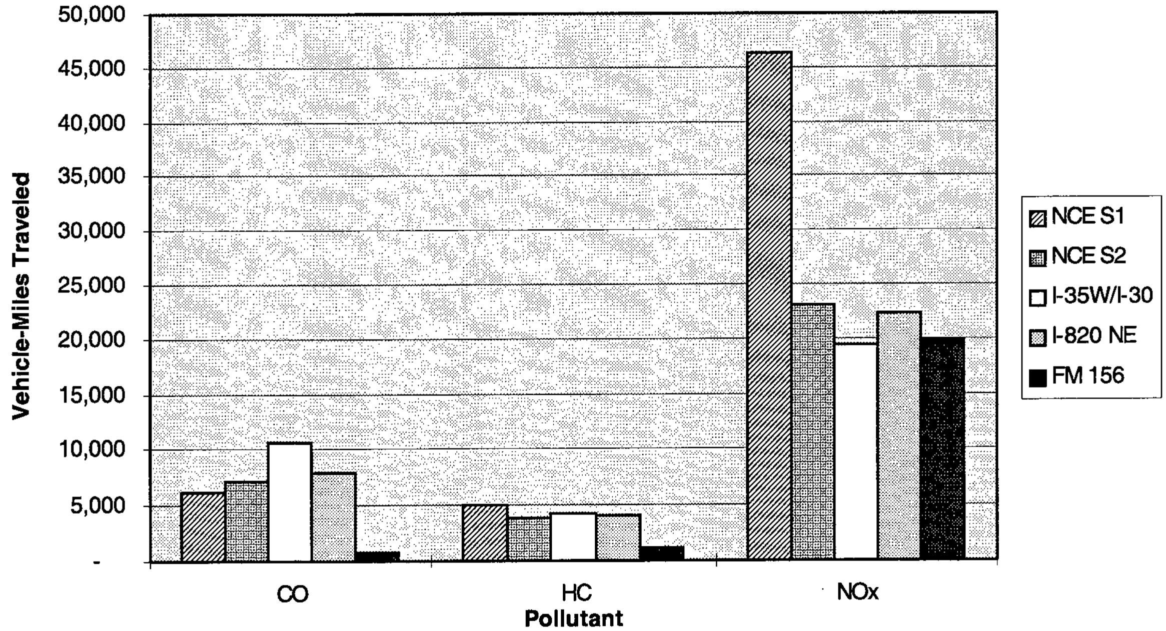


FIGURE 3-20. General Fleet VMT Equivalencies at 15 MPH

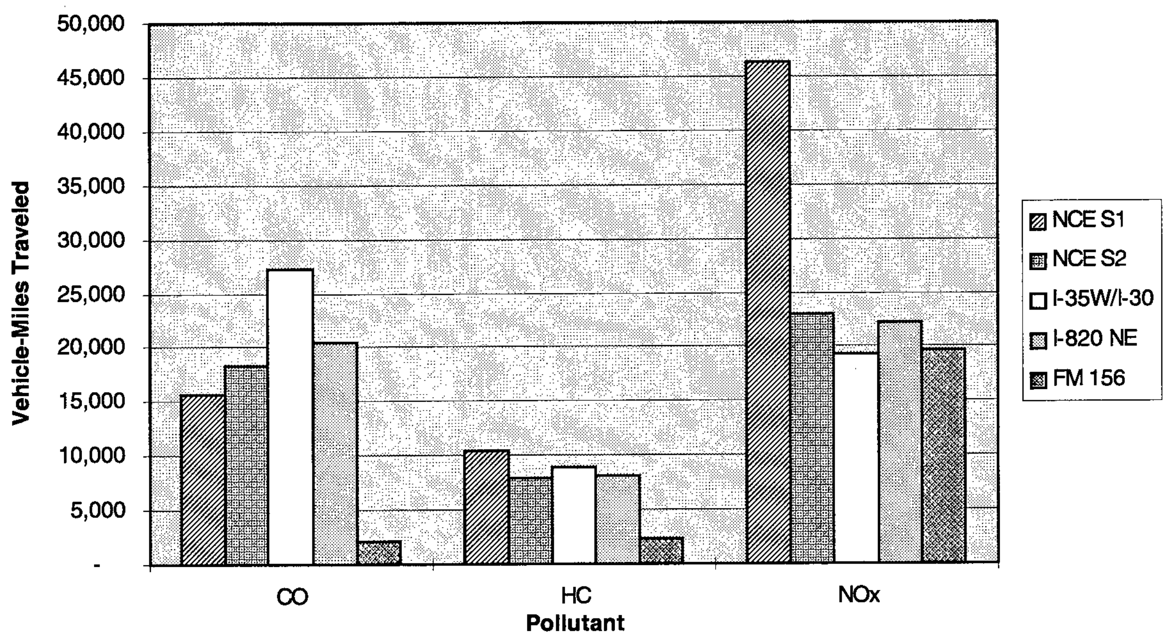


FIGURE 3-21. General Fleet VMT Equivalencies at 45 MPH

MOBILE SOURCE INVENTORY COMPARISON

The research team conducted further analysis to determine the contribution of highway construction project emissions to an urban nonattainment mobile source inventory. The analysis required two emissions values: (1) 1997 daily on-road mobile source emissions and (2) 1997 estimated daily nonroad construction emissions.

The 1997 daily on-road mobile source emissions were derived from vehicle-miles traveled estimates for Dallas and Tarrant counties. The VMT estimates were calculated using Federal Highway Performance Monitoring System (HPMS) data by functional class, this was calculated for both counties (Table 3-23).

TABLE 3-23
1997 DAILY VMT

County	Daily VMT (000,000)
Dallas	63.0
Tarrant	40.8
TOTAL	**103.8**

The team then calculated on-road mobile source emissions as the product of VMT and speed-specific emissions rates (derived from MOBILE) by functional class. The total emissions were calculated in tons for each of the three primary pollutants by county as shown in Table 3-24. Dallas County shows higher total emissions because this county has higher VMT levels than those in Tarrant County.

TABLE 3-24
1997 DAILY ON-ROAD MOBILE SOURCE INVENTORY

County	Tons of Emissions		
	CO	VOC	NOx
Dallas	788	160	108
Tarrant	474	96	65
TOTAL	**1,262**	**256**	**173**

Next, the team calculated daily nonroad construction emissions. The team generated these estimates from (1) estimates of daily construction activity during summer months for each county given by Fort Worth and Dallas District personnel (11,12), and (2) field data collected and processed for this report.

This activity was estimated activity in terms of average daily construction projects classified as a major or minor activity (Table 3-25). Major activity indicates activity such as the four large sites observed in this study. Minor activity represents the small maintenance project observed.

TABLE 3-25
AVERAGE DAILY CONSTRUCTION CONTRACTS

County	Project Classification	
	Major	Minor
Dallas	33	35
Tarrant	8	40

The team averaged emissions production for each of the study sites observed in this report, and applied to the average construction activity data supplied in the table above. The average emissions values used to produce countywide construction emissions estimates are shown in Table 3-26. At this point in the analysis, HC emissions are grouped as VOC.

TABLE 3-26
AVERAGE CONSTRUCTION EMISSIONS BY PROJECT CLASSIFICATION

Project Activity	Average Construction Site Emissions (lbs)		
	CO	HC	NOx
Major	426	27	147
Minor	46	7	104

Countywide estimates of construction emissions, in tons, are provided in Table 3-27. Nonroad construction emissions are higher in Tarrant County because there are significantly more minor activity projects.

TABLE 3-27
1997 ESTIMATED DAILY NONROAD CONSTRUCTION EMISSIONS

	Emissions (tons)		
County	CO	VOC	NOx
Dallas	7.8	0.6	4.2
Tarrant	3.1	0.3	2.8
TOTAL	**10.9**	**0.9**	**7.0**

The combined emissions results are shown in Table 3-28. The two emissions sources were reduced to their respective percentage contributions for each pollutant in each county and totaled each county. Construction emissions contribute 0.9% of the total mobile CO inventory, 0.5% of the total mobile VOC inventory, and 2.7% of the total mobile NOx inventory. Figures 3-22 through 3-24 graphically represent the emissions resulting from highway construction projects in comparison to all other on-road emissions.

TABLE 3-28
MOBILE SOURCE CONTRIBUTIONS

County	Pollutants					
	CO		VOC		NOx	
	On-Road	Construction	On-Road	Construction	On-Road	Construction
Dallas	99.0 %	1.0 %	99.5 %	0.5 %	97.4 %	2.6 %
Tarrant	99.4 %	0.6 %	99.6 %	0.4 %	97.1 %	2.9 %
TOTAL	**99.1 %**	**0.9 %**	**99.5 %**	**0.5 %**	**97.3 %**	**2.7 %**

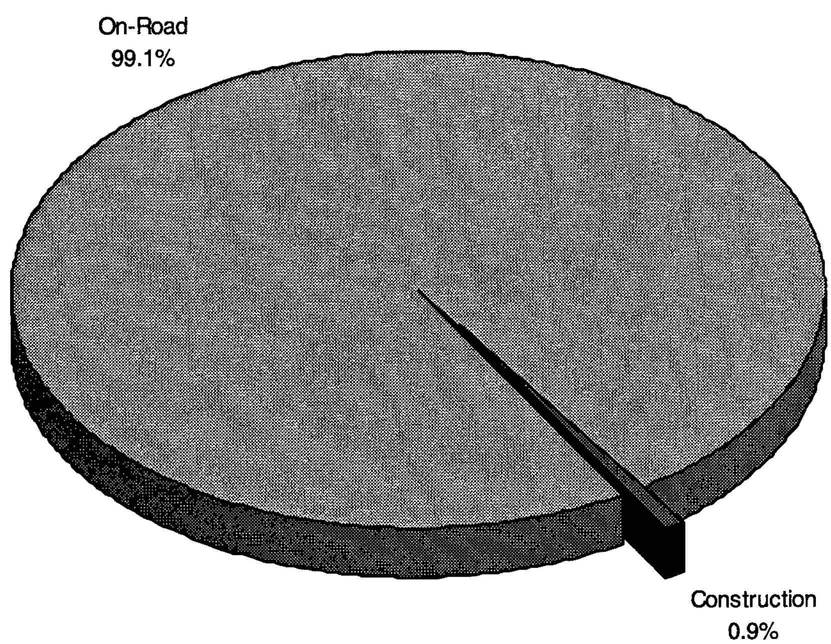


FIGURE 3-22. Dallas-Tarrant Counties Mobile Source Emissions Inventory: CO

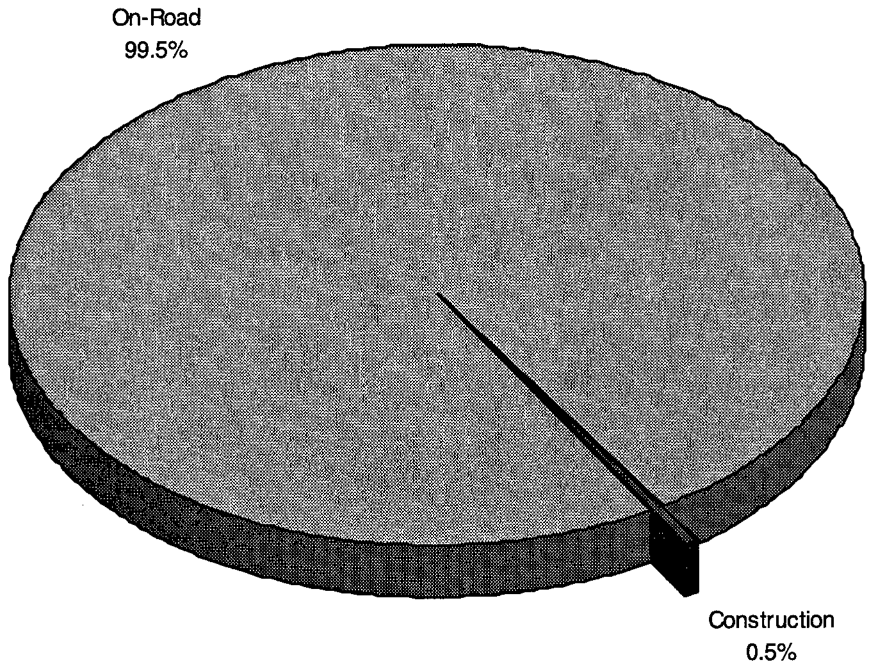


FIGURE 3-23. Dallas-Tarrant Counties Mobile Source Emissions Inventory: VOC

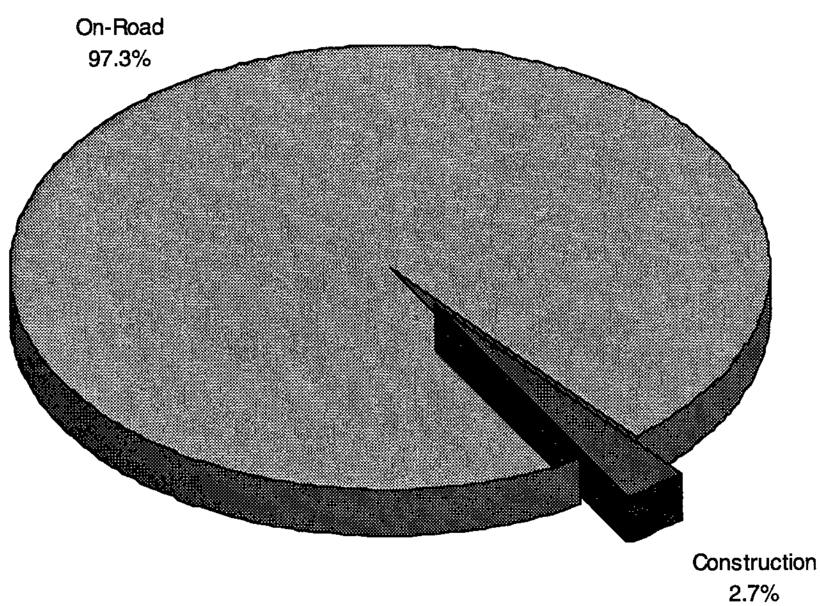


FIGURE 3-24. Dallas-Tarrant Counties Mobile Source Emissions Inventory: NOx

The team conducted a sensitivity analysis to determine what amount of construction activity is required to increase the input of contributions to 5% and 10% levels. This sensitivity testing assumed that only major construction projects in Dallas and Tarrant counties would contribute to the total nonroad construction emissions. The results of this analysis are shown in Table 3-29.

TABLE 3-29
SENSITIVITY ANALYSIS OF CONSTRUCTION ACTIVITY TO TOTAL MOBILE SOURCE EMISSIONS INVENTORY CONTRIBUTIONS

	Number of Major Projects Required to Contribute to Mobile Source Emissions Inventory					
	CO		VOC		NOx	
County	**5 %**	**10 %**	**5 %**	**10 %**	**5 %**	**10 %**
Dallas	195	411	423	892	115	242
Tarrant	118	247	254	537	68	144

As shown in this table, a significant level of major construction activity is required to increase the contribution of nonroad construction projects to level of 5% or 10% of the total mobile source emissions inventory. It is unlikely that activity would reach this level due to limits of project funding, state and construction resources, and motorist's acceptable construction-related traffic congestion tolerances. Therefore, this supports and validates the original hypothesis that emissions from construction sites are insignificant.

THROTTLE ACTIVITY

Research efforts to quantify the emissions impacts from transient operation (represented by high frequencies of engine throttles) of passenger and commercial vehicles are underway at several institutions around the nation. These institutions include the Georgia Institute of Technology and the University of California at Davis. Interim results from efforts, such as those at the Georgia Institute of Technology, indicate that transient operations result in a significant increase in a vehicle's emissions. The link between transient operation and increased emissions may apply to construction equipment engines and would additionally apply to materials trucks and field trucks at construction sites.

The team recorded engine throttles from the visual observation of PM emitted from exhaust pipes of materials trucks and construction equipment at each study site. The team did not record engine throttles from field trucks. These events represent hard throttles during transient operation. The visual observation method does not fully record the transient operation of vehicles or equipment. Throttling may occur without the production of PM, or an extended duration throttle may only produce visible emissions at the beginning of the throttle cycle. Because of these limitations, engine activity and any methods used to surrogate activity to emissions would under represent emissions from by transient operations.

Because of the lack of results and reports from the national research efforts mentioned above, the team did not use any of the throttle information collected for this research project in any of the activity or emissions analysis. The information is provided here, and in substantially more detail in Appendices A and B, for information purposes only. Brief discussions follow for both the materials truck and construction equipment categories.

Materials Trucks

Of the nine total materials trucks activities observed, the team collected information for six of these activities. Partial data was collected for two of these six activities. Therefore the throttle information collected from materials trucks is incomplete, but still yields some interesting data.

Appendix A includes a summary table of the observed throttling activities of materials trucks recorded at the five study sites. The table provides the number of trucks observed, frequency of throttles, and duration of throttles. The table also shows the total, average, standard deviation, minimum, and maximum for both the frequency and duration of throttles. A three-dimensional histogram shows the variation of throttles per materials truck observed by activity observed.

Two activities had a significant number of throttles: delivery of concrete (I-35W/I-30) and delivery of asphalt (FM 156). Both of these activities required several materials trucks arriving on-site at regular intervals. In some cases, the headway between trucks may have been a few minutes. However, both activities were of a long duration (greater than three hours).

The average number of throttles per truck ranged from 0.50 to 5.48. The highest observed value was at the I-35W/I-30 study site during concrete delivery for the elevated slab placement. The team observed the trucks throttling prior to unloading at the concrete pump. As the drivers cleaned their trucks on-site, the team observed additional throttling prior to the trucks returning to the concrete batch plant.

Construction Equipment

Transient operation was recorded from 50% of the construction equipment observed (Appendix B). The appendix includes several tables and three-dimensional line graphs displaying the frequency of throttle durations. The graphs are divided by AP-42 class.

The tables, divided by AP-42 class, include several statistics. These are throttle observations, duration, average duration from each piece of equipment, throttles per hour, and the proportion of transient operation to operating hours.

The three-dimensional graphs show the frequency of throttle durations, in seconds, for each piece of equipment grouped by AP-42 class. Most equipment shows throttle durations less than 5 seconds. The graphs also indicate that equipment throttle durations grossly follow a negative exponential distribution for equipment with a significant amount of throttling. This is shown in several pieces of equipment over many AP-42 classes.

Approximately half of the Misc class equipment produced throttle activity that appears extremely lower than some equipment that produced high levels of throttle activity. Most Rollers did not produce high level of throttle activity. This low activity level may result from the limitations of visual observation. Operators may have made throttles, but a significant amount of PM was not produced and therefore not observed.

CHALLENGES

Collecting data at highway construction projects is challenging. The challenge increased as the size and variety of activities at the project sites increased. A discussion of some of the challenges follows. The impacts of these challenges on data collection efforts are also noted.

Site Sizes

The physical size of some study sites proved challenging to the observation team. In particular, the size of the two North Central Expressway sites made it difficult to deploy observers over the project. At these sties, the size and physical terrain made it difficult to observe all activities within a reasonable proximity. Increasing the visual coverage of the area with additional observers could have minimized this.

Limited Accessibility

Many of the study sites had limited safe access for the observation team. Limited safe access is defined as locations where observers could visually record activity without interferring with normal construction activity, or placing an observer in unnecessary danger. In many cases, the limited safe access required observers to locate themselves some distance away from the actual activities being observed. Team members used binoculars to better view these activities from long distances. In some cases, very few, equipment was not in a viewable area and operated without being recorded by the observation team.

Numerous Subcontractors

Numerous subcontractors were on-site at each of the four large construction projects. Coordination with these subcontractors to record their activity proved too challenging for this study. This lack of coordination resulted in no data being collected from their subcontractors' field trucks; but, when visible, the observation team recorded equipment activity. Therefore, the emissions production of these subcontractors was not fully assessed in this study.

Portability of Small Engines

Recording portable small engine activity was also challenging for the observation team. Because this equipment has limited markings for identification, combined with the ease of transporting the equipment around the study site, it was difficult to track and observe its use. Activity and emissions from these small engines is possibly underrepresented in this analysis.

Engine Starts

Construction equipment engine starts were difficult to record. Visual observation from distances further than 100 feet from the equipment prohibited the team from accurately recording engine starts. Within 100 feet, the team used audible cues to record engine starts. These experiences indicated that audible cues are more important than visual cues in collecting engine start data.

Refueling Activity

The observation team recorded only a few refueling events at the study sites. The lack of this data may have resulted from a lack of observers at the projects' field offices where fuel is typically stored, or that these activities occurred after the observation team left the study site. Coordination with the contractor would have led to better data collection of this activity.

Chemical Use

The most challenging task, and the task where the least amount of information was collected, was the collection of chemical use data at the study sites. The observation team was never close enough to any activity to fully assess the chemical types or the amount used. The contractor at each site can provide better estimates of type and use for this activity.

Prime Contractor Cooperation

On some sites, the prime contractor exhibited resistance, in fear of some regulatory enforcement action. Other prime contractors were more willing to assist with data collection. After fully explaining the position and intent of the research team, the prime contractors agreed to participate in the data collection effort. This communication was an essential element to the success of the study. Cooperation of the prime contractors improved data collection efforts and enabled the team to develop useful results from this study.

CHAPTER IV. CONCLUSIONS

This chapter presents the conclusions developed by the research team based on the results of this study. The discussion follows the same path presented in the previous chapter.

ACTIVITY AND EMISSIONS FROM FIELD TRUCKS

Contractors use conventionally fueled trucks, and typically choose diesel-fueled vehicles. TxDOT uses both conventional gasoline-fueled vehicles and clean- or dual-fueled trucks. The use of clean vehicles is a result of mandates and clean air goals adopted by government. The majority of model years for both contractors and TxDOT field trucks were mid- to late-1990s.

Contractors' field trucks running times increased as the size and complexity of the construction site increased. Contractors typically operated their field trucks 30% to 80% longer than TxDOT operated their field trucks, and they started their engines 30% to 50% more than their TxDOT counterparts. Contractors made a greater number of cold starts, but both contractors and TxDOT made similar amounts of hot starts.

Running emissions are the major source of emissions from field trucks. Despite this, the total emissions from field trucks is small compared to other sources at the construction site.

ACTIVITY AND EMISSIONS FROM MATERIALS TRUCKS

The average on-site times for materials trucks ranged between 0.03 hours to 0.59 hours. Typical on-site times averaged 0.20 hours, or 12 minutes, which is a short headway.

A review of emissions from materials trucks indicates that these emissions are less than emissions generated by field trucks. Therefore, the contribution of materials trucks to a site's total emissions is small or insignificant.

ACTIVITY AND EMISSIONS FROM CONSTRUCTION EQUIPMENT

Gasoline-fueled equipment observed hours of use ranged from 10% to 65% of the hours of use observed for diesel-fueled equipment. This proportion decreased as the hours of use for diesel-fueled equipment increased. A majority of the gasoline-fueled equipment used at the sites was included in the AP-42 Misc class and was limited to light-duty equipment.

The research team may have overestimated emissions from construction equipment because no engine loading data was available. Therefore, the emissions rates used represent the rate of emissions produced while an engine is under full load. Observations made in the field indicate that the equipment did not operate under fully loaded conditions during total operating time.

Construction equipment produces CO emissions in greatest quantities, followed by NOx and HC emissions respectively. HC emissions from each site were relatively insignificant when compared to the other two primary pollutants. The contribution of gasoline-fueled equipment to CO emissions was greater than the contribution from diesel-fueled equipment. The team attributes this to the higher number of gasoline-fueled, light duty pieces of equipment in the AP-42 Misc class.

Emissions from actual construction equipment represents the largest fraction of emissions produced from a highway construction project. Still, the quantity of emissions, even from construction equipment, is relatively small in comparison to regional emissions inventories.

TOTAL EMISSIONS AT THE SITE

The following section summarizes the emissions contribution from each highway construction project's source. Discussion on other observations from the previous chapter is also included.

The contribution of field trucks, materials trucks, and construction equipment to a highway construction site's total emissions is provided in Table 4-1.

TABLE 4-1
HIGHWAY CONSTRUCTION PROJECT EMISSIONS SOURCES

Pollutant	Percent Contribution		
	Field Trucks	Materials Trucks	Construction Equipment
CO	5 - 10	1 / 5[1]	90 - 95
HC	10 - 15	1 / 5[1]	85 - 90
NOx	1 - 2	1	95 - 99

Note: [1] Large construction projects / small construction projects

The following are observations developed from the data included in this report concerning emissions produced at a highway construction project:

1. *NOx emissions decrease and CO emissions increase as activity at a site progresses from earthwork to structural work, such as workers pouring concrete or pavement.* The research team did not find a correlation with HC.

2. *Total site emissions appear to increase as activity at a site progresses through its construction schedule to some point at which activity diminishes and the total daily emissions decrease.* Evidence from similar study sites in different phases of construction provided some limited evidence of this relationship.

3. *Structural work appears to result in higher emissions when major milestones are being met.* The increase in emissions might result from increases in construction activity for one or more critical tasks to meet milestones. For example, a large-scale effort to place concrete on an elevated section requires the use of many different pieces of equipment.

4. *Total emissions for each of the three primary pollutants were less than one ton.* This is a small amount of pollutants when compared to the hundreds of tons in regional emissions

inventories. In fact, HC emissions from the five study sites totaled 0.1 tons and Nox emissions totaled less than 0.3 tons.

SOURCES OF POTENTIAL ERROR

The emissions estimates provided in this report are subject to several sources of potential error. These sources may under- or over-estimate the emissions from a highway construction site.

Underestimating emissions at a construction site may have occurred from any of the following 10 reasons:

1. *Lack of start emissions for construction equipment was experienced.* Start emissions contribute, in some cases significantly, to a passenger vehicle's total trip emissions. This information is not available for construction equipment. Generalizing from the behavior of other engines, the team believes start emissions would also significantly contribute to the equipment's total emissions production.

2. *Transient operations were not assessed.* Recent research has shown that transient operations such as frequent throttle events can greatly increase the emissions rates of passenger vehicles. By applying this same concept to construction equipment, it is believed that transient operations can greatly increase the emissions production from construction equipment.

3. *Loss of observations was experienced due to inadequate manpower and portability of small equipment.* Some data was not captured due to the size of the construction sites and the portability of smaller equipment pieces, such as generators to operate small hand-held tools. Although the observation team actively sought to observe and record the use of this equipment, some construction activities were missed.

4. *Partial data was collected from subcontractors.* The observation team sought to record data for all construction equipment at each study site. In most cases, the team observed and recorded construction equipment used by subcontractors. However, the use of field trucks by the subcontractors was not recorded due to difficulties in coordination.

5. *Effects of vehicle queuing were not included in the analysis.* One of the previously identified impacts of highway construction projects is its influence to traffic at the construction site or on surrounding streets. Contractors use lane closures as a common means to provide safety buffers for both construction workers and the driving public. If the emissions associated with vehicle queuing are added to a construction site's total emissions, significant increases in total emissions may result.

6. *No assessment made of emissions from on-site fuels and chemicals were used.* Because of the difficulty in observing construction activities in very close proximity, it was difficult for the observation team to adequately observe and record the type and amounts of fuel and chemicals used. The research team believes there is a limited amount of chemicals and fuel used at the site, therefore contributing little to a site's total emissions.

7. *No assessment made of emissions from construction materials such as paints or asphalts were used.* Only one of the study sites had asphalt delivered to the construction site. The team did not record the quantities of materials delivered and emissions from these materials were not estimated. The team received some guidance early in the report for assessing the emissions produced from cutback asphalt. It is possible that the use of some of these materials can greatly contribute to a construction site's total emissions production based on the size of the construction project, construction activity, and amount of materials used.

8. *Materials trucks on-site times may be less than actual.* The on-site times recorded for materials trucks may not accurately represent the duration of time they were on each

study site. This error resulted from the challenges faced by the limited number of observation personnel and the size and physical geometry of a construction site. In some cases, the team collected very accurate on-site data for the materials trucks. The on-site times for materials trucks may be slightly higher than those provided in the previous chapter, but the incremental change in emissions is insignificant.

9. *No VMT-related emissions for materials trucks traveling to and from the construction site were considered.* Materials trucks traveling from an off-site location, such as a batch plant or dumping ground, generate VMT-related emissions. The team did not consider these emissions in this analysis. Depending on the length of the trip off-site and the average speed of the materials trucks traveling to and from that off-site location, VMT-related emissions can vary greatly. A more thorough analysis should examine these emissions and their contribution to the construction site's associated emissions.

10. *Emissions from stationary sources used at the construction site were not included in the analysis.* This includes emissions generated by batching (concrete or asphalt) plants. These emissions are associated with the construction site and may or may not be on-site. In most cases, the batch plants are not on-site, but are several miles away. Although the emissions from these stationary sources were not included in this analysis, a more thorough analysis should consider these emissions sources.

The team may have over estimated the emissions at the construction sites for the following four reasons:

1. *Assumed workers used 100% of construction equipment's available power.* This was an assumption that the team could not avoid due to the limited amount of data provided for analysis. As stated previously, this assumption results in the highest emissions rate for

the analysis. In many cases, visual observation of construction equipment revealed that workers did not operate the equipment at high engine load levels during operating hours.

2. *Data was collected on high activity days.* In some cases, the team collected data at the study sties when major milestones were being met. This resulted in very intense construction activities that may or may not have resulted in an overestimation of that study site's emissions. Capturing this intense activity was not specifically sought for this study. Observations of study sites were chosen at random without any regard to the types of construction activities occurring that particular day.

3. *Average speed assumed for field trucks may be too low.* The average speed assumed for field trucks may be too conservative. The field trucks may have averaged higher speeds at the study sites, but that specific information was not collected from the contractors or TxDOT.

4. *Running times of construction equipment may be longer than actual.* The observed and recorded running times of construction equipment may be longer than that recorded on the equipment's hour meters. In most cases, the contractors were asked to provide the research team with a list of equipment and hours of use, collected directly from the equipment, for the day the study site was observed. In some cases, the team did not find any logged engine hours of use for equipment they observed operating at the construction site. The equipment was identified from marking painted on the equipment, but no engine hours of use appeared on the contractor's report.

CONSTRUCTION SITE EMISSIONS EQUIVALENCIES

The research team made an effort in this report to place the emissions produced at highway construction projects in some perspective. One method used related emissions to VMT equivalents.

The emissions generated by the four large construction sites produced VMT equivalencies shown in Table 4-2.

TABLE 4-2
VMT EQUIVALENCIES OF HIGHWAY CONSTRUCTION PROJECTS

Pollutant	VMT (000s) Equivalencies by Project Size	
	Small	Large
CO	2	10 - 30
HC	2	5 - 10
NOx	20	20 - 50

These equivalencies represent the general vehicle fleet traveling at average speeds between 15 MPH and 45 MPH. When assuming higher average speeds, the VMT equivalencies increase for CO and HC pollutants.

MOBILE SOURCE EMISSIONS INVENTORY COMPARISONS

Another method of placing highway construction emissions in perspective is a comparison with emissions inventories. An emissions inventory was created for Dallas and Tarrant counties based on-road mobile sources and highway construction emissions. The team expanded the highway construction emissions in each county based on contract activity provided by TxDOT. This resulted in several important observations.

First, Tarrant County nonroad construction emissions were higher than emissions in Dallas County. The team attributes this difference to a significantly higher amount of minor highway construction projects in Tarrant County.

Second, the team found that construction emissions contribute to 0.9% of the CO inventory, 0.5% of the VOC inventory, and 2.7% of the NOx inventory. While the total mobile source emissions inventory was not identified in this report, the contributions from highway construction projects shown here would decrease as additional nonroad mobile emissions sources are added to the inventory.

Third, for construction-related emissions to reach contribution levels of 5% or 10%, a significant level of major construction activity is required. It is unlikely that construction would ever reach this level. Therefore, highway construction emissions are insignificant to regional emission inventories.

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APPENDIX A

OBSERVED THROTTLE ACTIVITIES OF CONSTRUCTION MATERIALS TRUCKS

TABLE A-1
THROTTLE FREQUENCY OF MATERIALS TRUCKS

Study Site	Activity	Trucks Observed	Throttle Frequency				
			Total	Average	Std. Dev.	Min.	Max.
NCE S-1	Haul Spoils	114	61	0.54	0.74	0	3
	Deliver Lime	16	17	1.06	1.06	0	3
NCE S-2	Deliver Concrete	18	44	2.44	0.78	1	4
I-35W/I-30	Deliver Concrete	27	148	5.48	2.21	2	10
I-820 NE	Deliver Fill	8	4	0.50	1.41	0	4
FM 156	Deliver Asphalt	57	131	2.30	4.80	0	23

TABLE A-2
THROTTLE DURATION OF MATERIALS TRUCKS

Study Site	Activity	Trucks Observed	Throttle Duration (sec)				
			Total	Average	Std. Dev.	Min.	Max.
NCE S-1	Haul Spoils [1]	114	n/a	n/a	n/a	n/a	n/a
	Deliver Lime	16	39	2.29	1.31	1	5
NCE S-2	Deliver Concrete	18	84	1.91	0.94	1	5
I-35W/I-30	Deliver Concrete [2]	27	75.52	1.30	0.57	0.17	2.67
I-820 NE	Deliver Fill	8	7	1.75	0.96	1	3
FM 156	Deliver Asphalt [1]	57	n/a	n/a	n/a	n/a	n/a

Notes: [1] No throttle duration data collected for these activities
[2] Values represented are hours

TABLE A-3
THROTTLE CHARACTERISTICS OF MATERIALS TRUCKS ACTIVITIES

Material Truck Activity	Number of Activities Observed	Number of Material Trucks Observed	Total On-Site Hours	Average On-Site Hours per Vehicle	Average Task Duration (hrs.)	STD	Minimum Value Observed (min.)	Maximum Value Observed (min.)
Deliver Total	6	144	39.05	0.27	6.51	5.93	2.02	15.77
Soil-Lime	3	42	7.97	0.19	2.66	0.72	2.02	3.44
Concrete	2	45	18.85	0.42	9.43	8.97	3.08	15.77
Asphalt	1	57	12.23	0.21	12.23		12.23	12.23
Removal Total	**3**	**155**	**17.71**	**0.11**	**5.90**	**5.98**	**0.73**	**12.45**

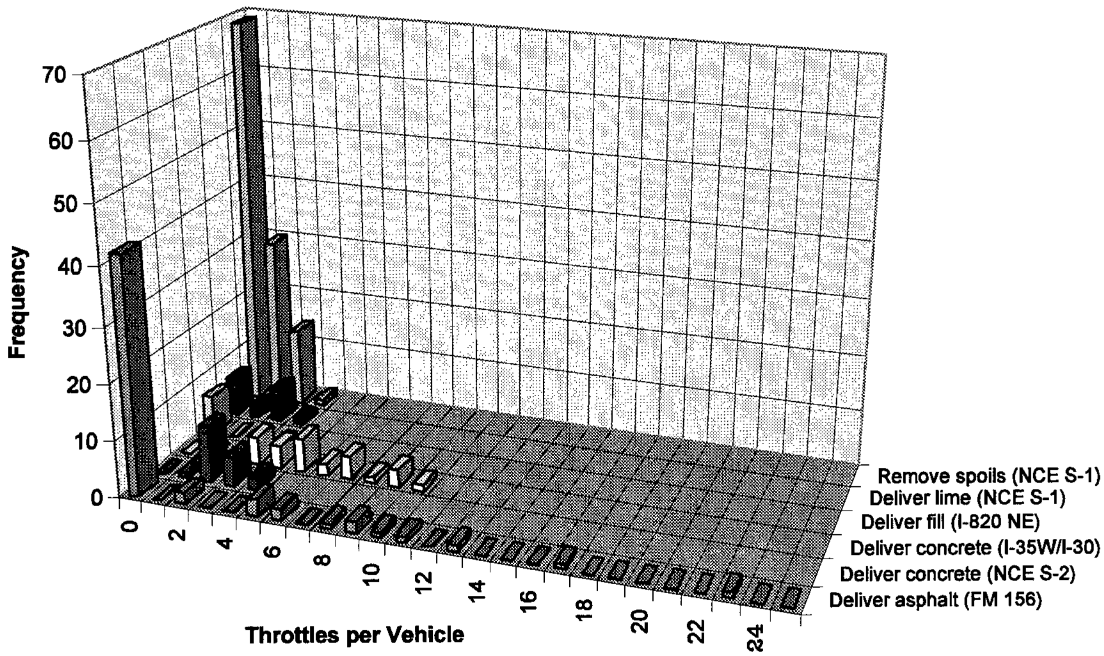

FIGURE A-1. Throttle Frequency Per Materials Truck Observed

APPENDIX B

OBSERVED THROTTLE ACTIVITIES OF CONSTRUCTION EQUIPMENT

TABLE B-1
THROTTLE ACTIVITY CHARACTERISTICS OF
AP-42 'OFF-HIGHWAY TRUCK' CLASS

	Observations (#)	Throttle Time (sec)	Average Throttle Duration (sec)	Throttles per Engine Hour (#/hr)	Throttle Duration Ratio (sec/hr)
Total	34	9,816			
Average	7	1,963	179	2	472
STD	6	2,647	209	1	632
Min	1	1	1	1	1
Max	14	5,148	468	4	1,353

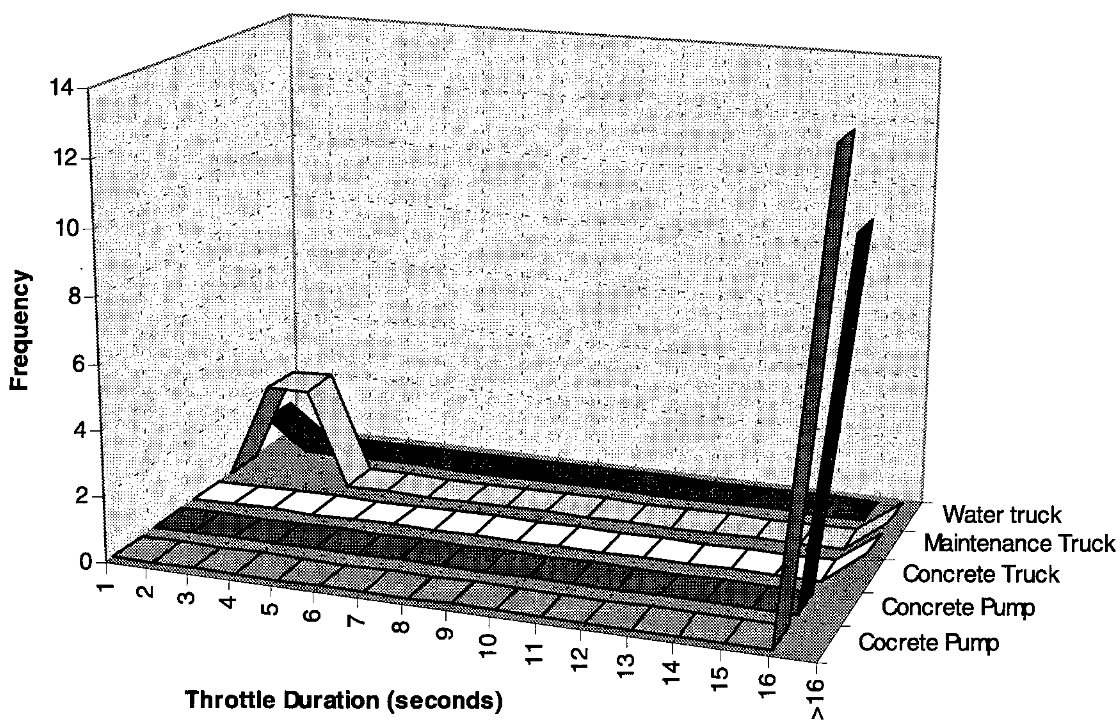

FIGURE B-1. Frequency vs. Throttle Duration for the AP-42 Off-Highway Truck Class

TABLE B-2
THROTTLE ACTIVITY CHARACTERISTICS OF AP-42 'MISC' CLASS

	Observations (#)	Throttle Time (sec)	Average Throttle Duration (sec)	Throttles per Engine Hour (#/hr)	Throttle Duration Ratio (sec/hr)
Total	1,190	8,853			
Average	48	354	6	22	101
STD	97	1,176	12	41	212
Min	1	3	0	1	1
Max	440	5,811	46	183	911

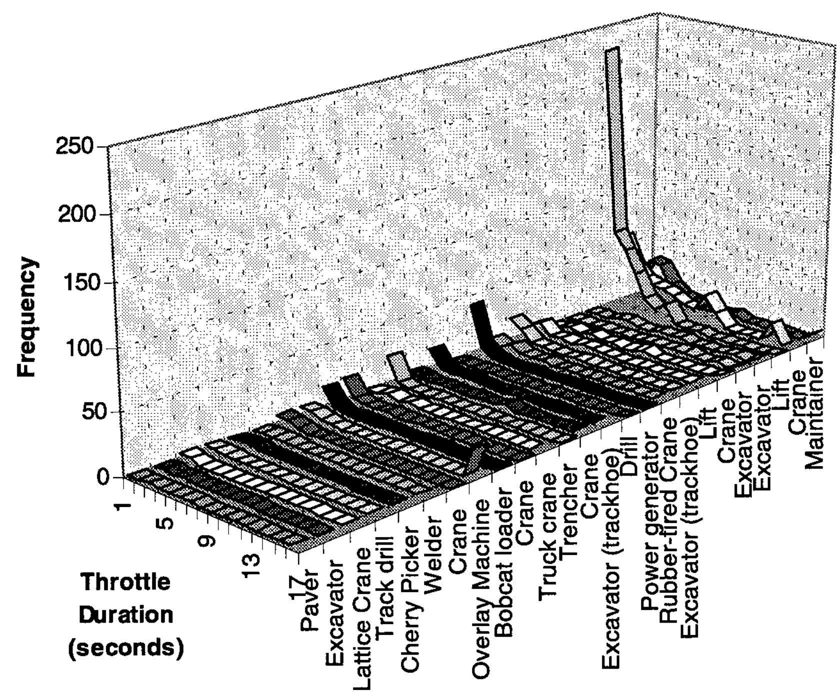

FIGURE B-2. Frequency vs Throttle Duration for the AP-42 Misc Class

TABLE B-3
THROTTLE ACTIVITY CHARACTERISTICS OF AP-42 'MOTOR GRADER' CLASS

	Observations (#)	Throttle Time (sec)	Average Throttle Duration (sec)	Throttles per Engine Hour (#/hr)	Throttle Duration Ratio (sec/hr)
Total	154	8,109			
Average	17	901	63	18	223
STD	15	1,621	141	24	277
Min	1	1	1	2	5
Max	43	4,330	433	80	839

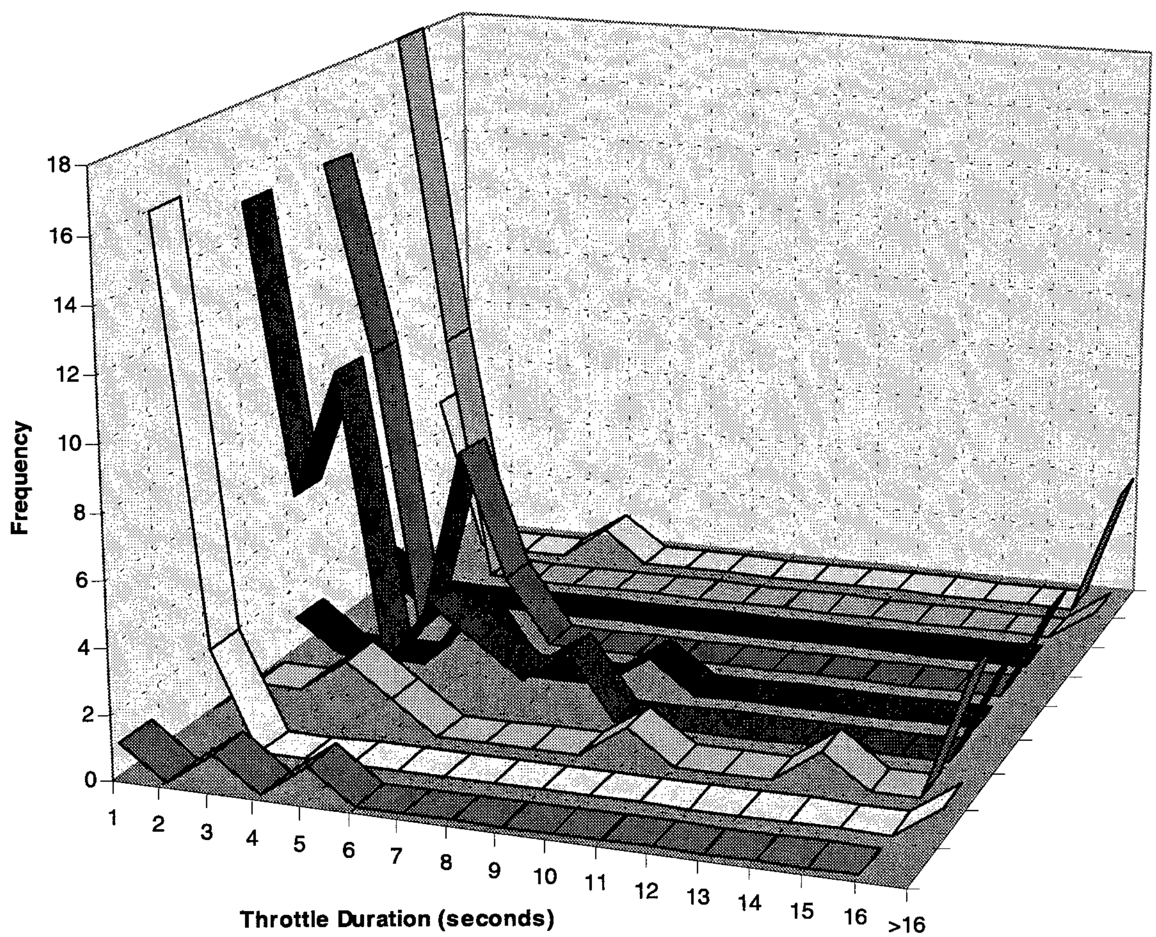

FIGURE B-3. Frequency vs. Throttle Duration for the AP-42 Motor Grader Class

TABLE B-4
THROTTLE ACTIVITY CHARACTERISTICS OF AP-42 'ROLLER' CLASS

	Observations (#)	Throttle Time (sec)	Average Throttle Duration (sec)	Throttles per Engine Hour (#/hr)	Throttle Duration Ratio (sec/hr)
Total	1,394	3,492			
Average	139	349	20	19	50
STD	340	837	56	45	111
Min	1	4	1	0	1
Max	1,100	2,721	180	147	363

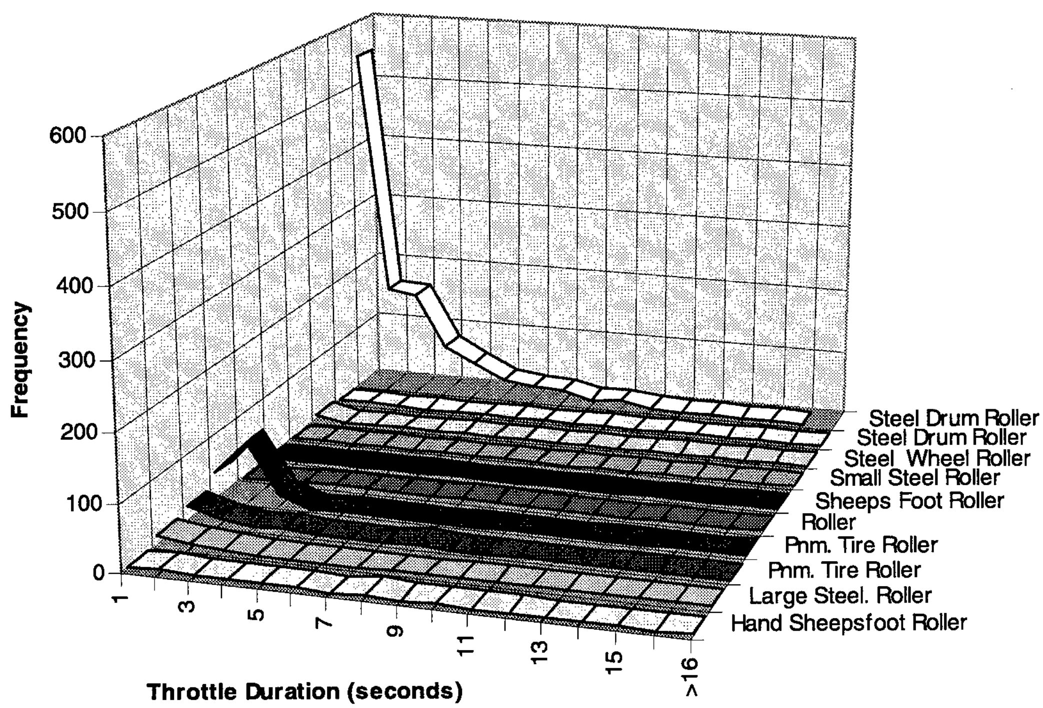

FIGURE B-4. Frequency vs Throttle Duration for the AP-42 Roller Class

TABLE B-5
THROTTLE ACTIVITY CHARACTERISTICS OF AP-42 'TRACK-TYPE TRACTOR' CLASS

	Observations (#)	Throttle Time (sec)	Average Throttle Duration (sec)	Throttles per Engine Hour (#/hr)	Throttle Duration Ratio (sec/hr)
Total	143	225			
Average	29	45	2	11	20
STD	26	34	1	10	19
Min	10	11	1	2	2
Max	71	96	2	26	46

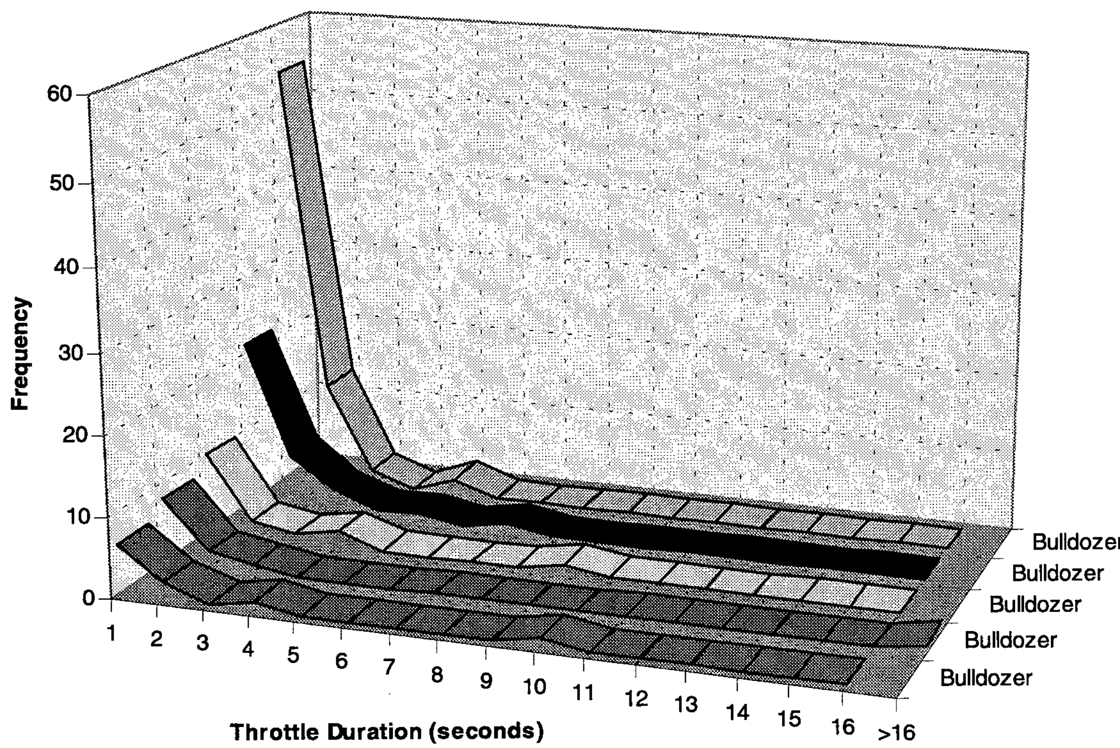

FIGURE B-5. Frequency vs Throttle Duration for the AP-42 Track-Type Tractor Class

TABLE B-6
THROTTLE ACTIVITY CHARACTERISTICS OF AP-42 'WHEELED LOADER' CLASS

	Observations (#)	Throttle Time (sec)	Average Throttle Duration (sec)	Throttles per Engine Hour (#/hr)	Throttle Duration Ratio (sec/hr)
Total	3,265	10,202			
Average	156	486	6	47	136
STD	287	936	16	59	187
Min	1	1	1	3	3
Max	1,184	4,103	76	210	826

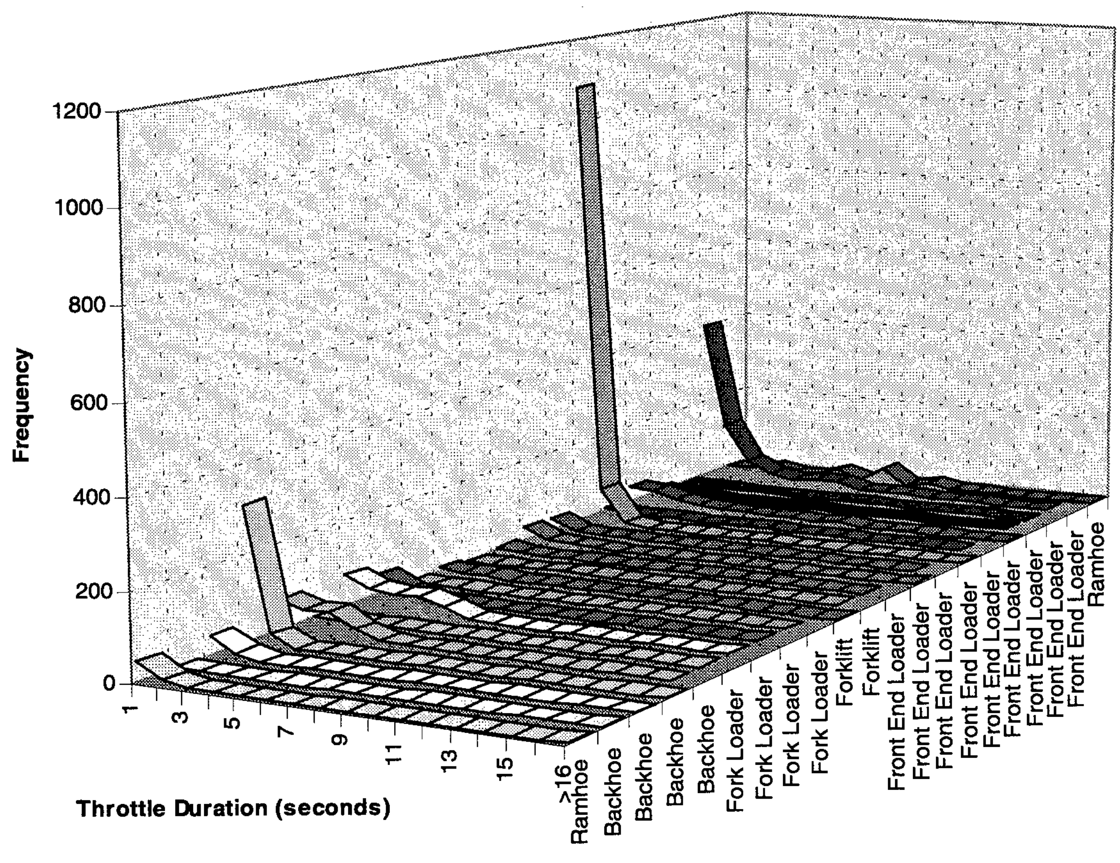

FIGURE B-6. Frequency vs. Throttle Duration for the AP-42 Wheeled Loader Class

TABLE B-7
AGGREGATED THROTTLE DURATION FREQUENCIES BY AP-42 EQUIPMENT CLASS

AP-42 Class	Duration of Throttles (sec.)																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	>16
Misc	463	199	140	86	56	41	33	21	33	28	1	5	0	2	20	0	62
Motor Grader	72	27	12	9	10	2	1	2	1	1	0	0	0	1	0	0	16
Off-Hwy Truck	1	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	27
Roller	639	280	189	92	61	33	25	31	11	13	3	1	2	0	3	0	11
Scraper	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Track-Type Loader	96	72	71	51	42	31	20	16	11	5	0	0	0	0	0	0	1
Track-Type Tractor	99	26	7	4	3	0	1	0	1	1	0	0	0	0	0	0	1
Wheeled Loader	2,222	462	214	113	58	58	30	47	12	26	2	5	2	1	1	0	12

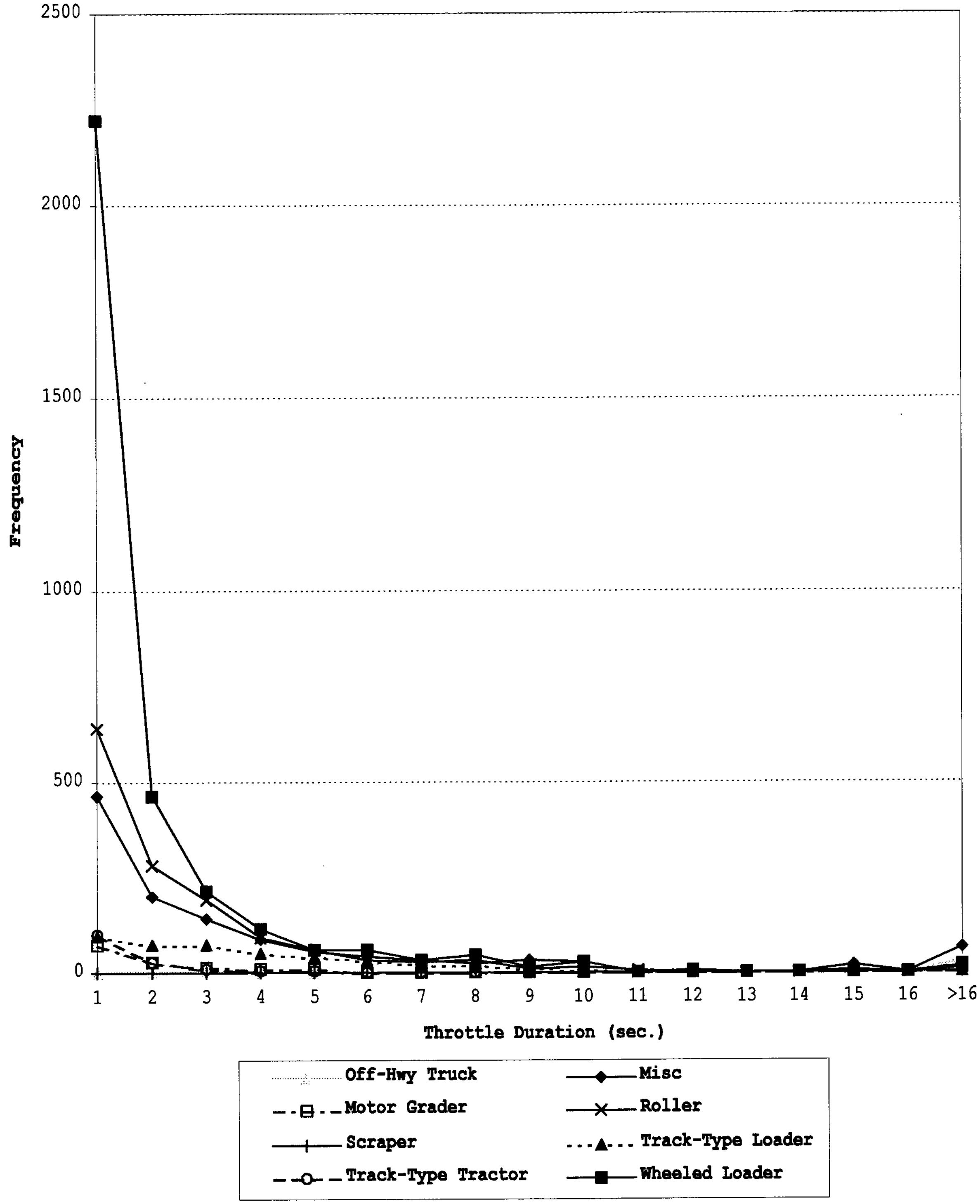

FIGURE B-7. Aggregated Frequency vs Throttle Duration by AP-42 Equipment Class

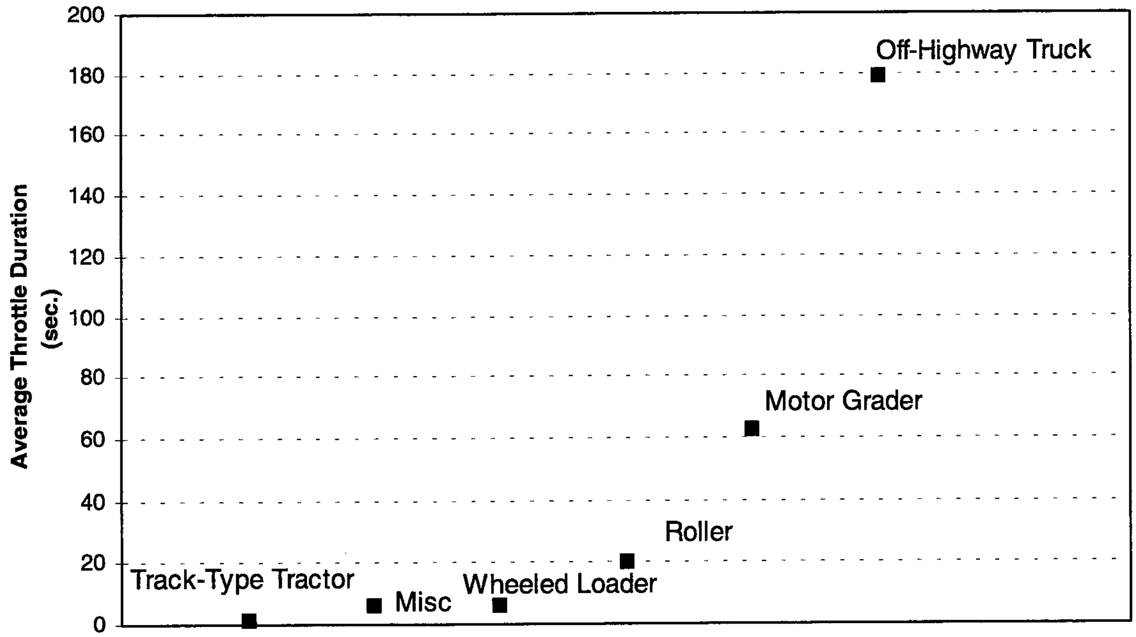

FIGURE B-8. Average Throttle Durations by AP-42 Equipment Class

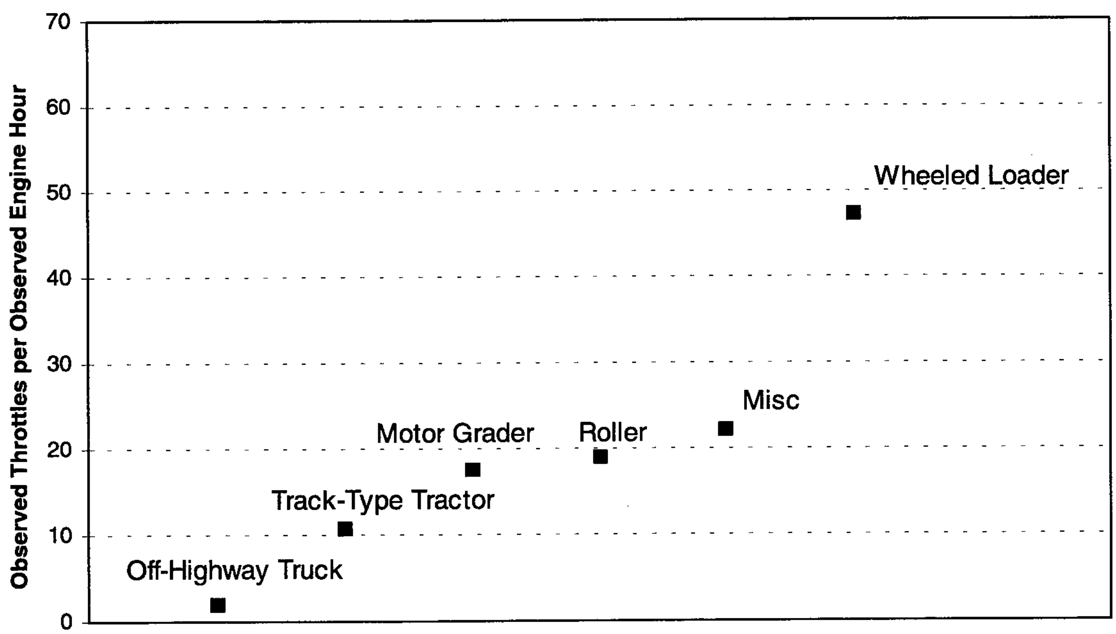

FIGURE B-9. Throttle Frequency Per Engine Hour of Use by AP-42 Equipment Class

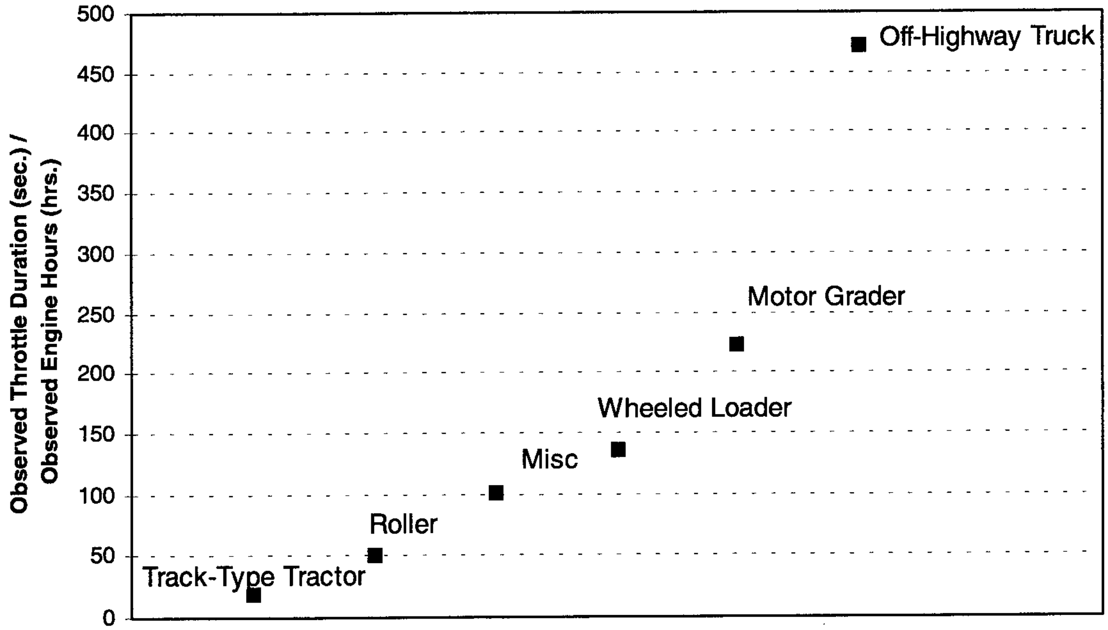

FIGURE B-10. Ratio of Observed Throttle Durations to Observed Engine Hours of Use by AP-42 Equipment Class

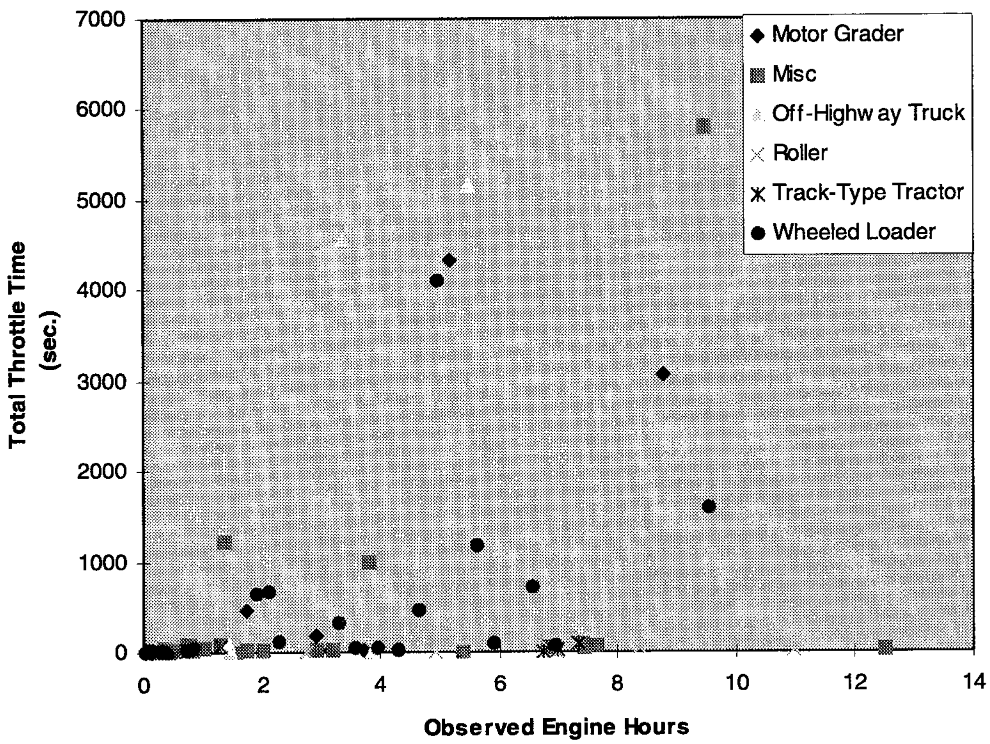

FIGURE B-11. Total Observed Throttle Time vs. Observed Engine Hours of Use by AP-42 Equipment Class

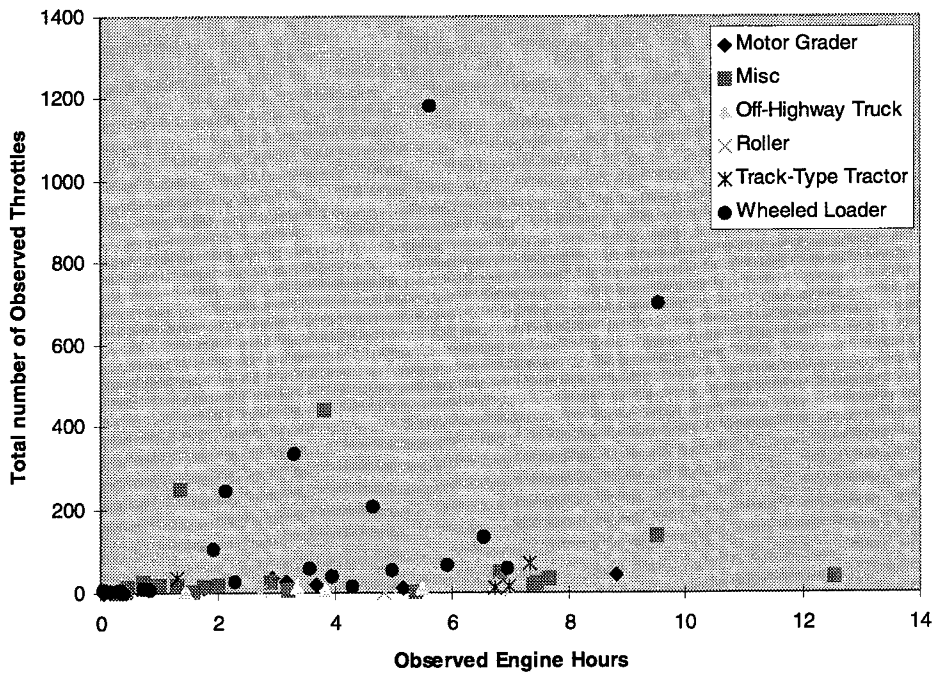

FIGURE B-12. Number of Observed Throttles vs. Observed Engine Hours of use by AP-42 Equipment Class

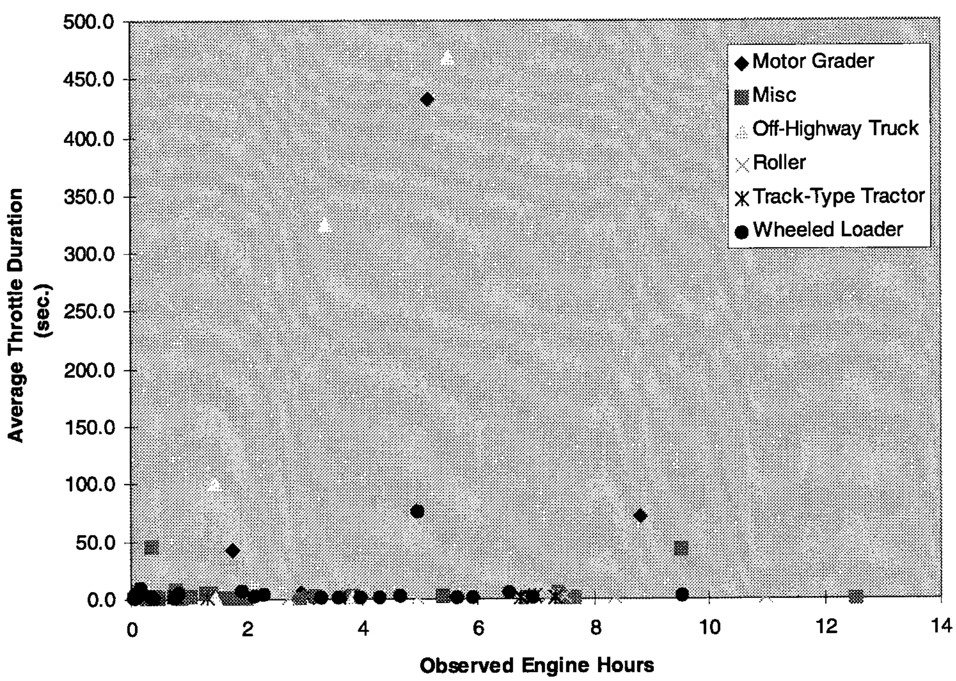

FIGURE B-13. Average Observed Throttle Duration vs. Observed Engine Hours of use by AP-42 Equipment Class

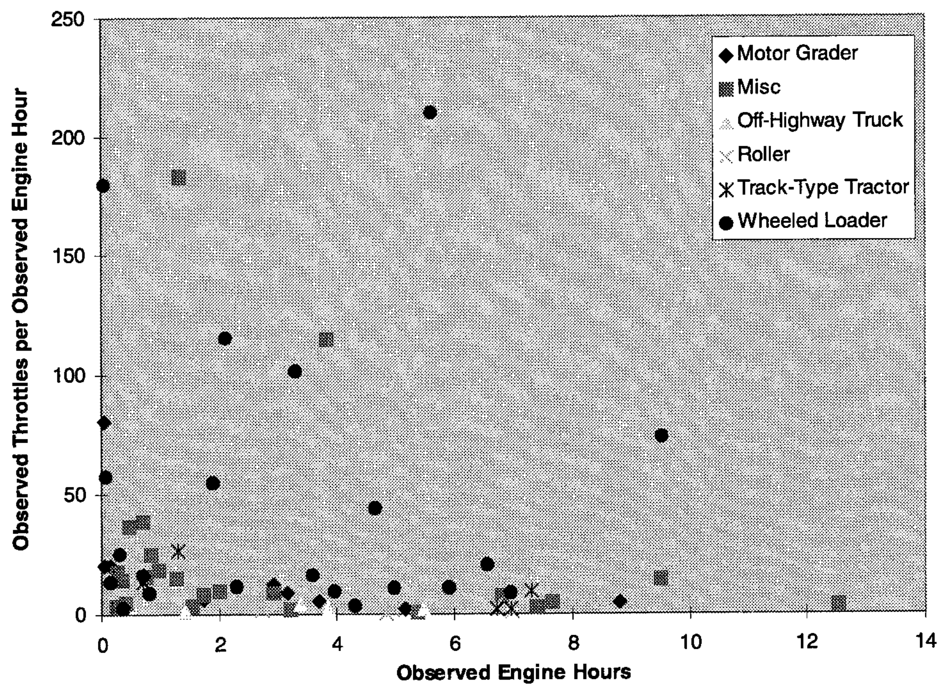

FIGURE B-14. Observed Throttle Frequency vs. Observed Engine Hours of use by AP-42 Equipment Class

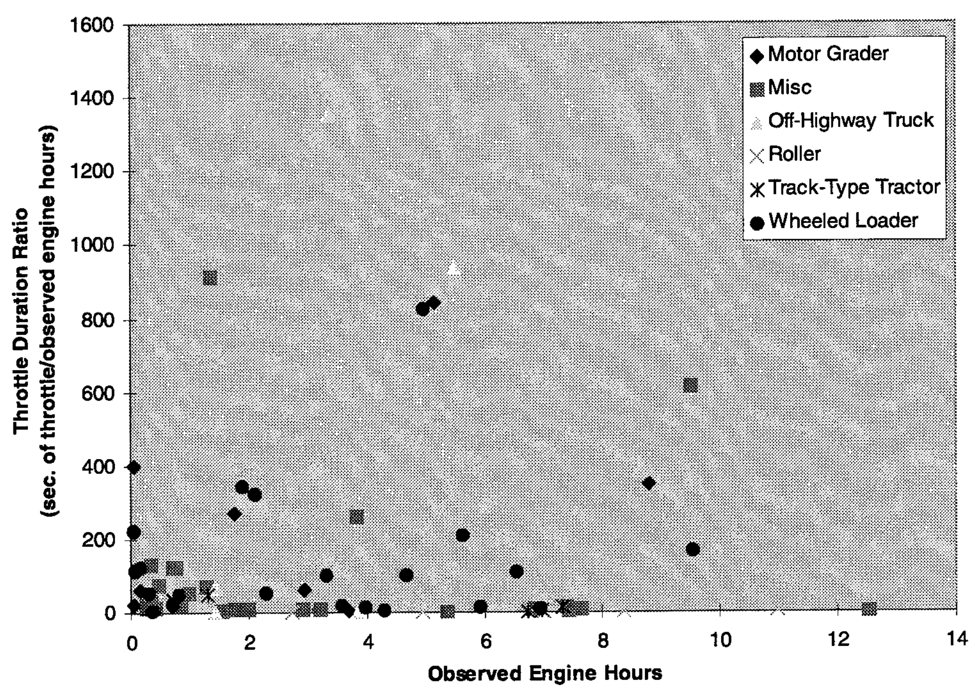

FIGURE B-15. Throttle Duration Ratio vs. Observed Engine Hours of use by AP-42 Equipment Class

APPENDIX C

CONSTRUCTION EQUIPMENT ACTIVITY DATA COLLECTION FORMS

TTI Research Project
Construction Activity Case Study

Vehicle Information:

Year: ____________ **Odometer Reading:**____________________

Make: ___________________________ **Model:** _____________________________

Fuel Type (circle one): **Gasoline** **Diesel**
0
Vehicle Start Information:

Please denote the times when the vehicle's engine was started and shut-off <u>each time</u> throughout the study day (_________________________)

Time Engine Started	Time Engine Shut-off
ex: 6:51a	ex: 7:07a

Time Engine Started	Time Engine Shut-off

Time Engine Started	Time Engine Shut-off

Time Engine Started	Time Engine Shut-off

Thank you for your participation!

TTI Research Project
Materials Truck Tracking Form

Date		Construction Site ID	
Activity		Location	

#	Make	Model	Time		Throttles
			In	Out	
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					
21					

#	Make	Model	Time		Throttles
			In	Out	
22					
23					
24					
25					
26					
27					
28					
29					
30					
31					
32					
33					
34					
35					
36					
37					
38					
39					
40					
41					
42					
43					

TTI Research Project
Construction Case Study Data Record

Date		**Construction Site ID**	
Activity Observed			
Observer		**Location of Observer**	
Start Time		**End Time**	

Equipment Type		
Make/Model		
Equipment ID (if known)		
Engine Hour Use	**Before**	**After**
Times Used (ex: 915a-9:30a)	1	8
	2	9
	3	10
	4	11
	5	12
	6	13
	7	14
Number of Equipment Starts	< 1 hour	> 1 hour
Throttle Events (Duration) NOTE: Put tick marks by each duration and record duration if > 10 sec	1 sec	
	2 sec	
	3 sec	
	4 sec	
	5 sec	
	6 sec	
	7 sec	
	8 sec	
	9 sec	
	10 sec	
	Other	
# of Refuelings (Exposed Fuel Duration		

Equipment Type		
Make/Model		
Equipment ID (if known)		
Engine Hour Use	**Before**	**After**
Times Used (ex: 915a-9:30a)	1	8
	2	9
	3	10
	4	11
	5	12
	6	13
	7	14
Number of Equipment Starts	< 1 hour	> 1 hour
Throttle Events (Duration) NOTE: Put tick marks by each duration and record duration if > 10 sec	1 sec	
	2 sec	
	3 sec	
	4 sec	
	5 sec	
	6 sec	
	7 sec	
	8 sec	
	9 sec	
	10 sec	
	Other	
# of Refuelings (Exposed Fuel Duration		

Observed Chemical/Petroleum-Based Material Use:			
Type	Brand/Name	Estimated Application Rate	Estimated Quantity

Other General Observations:	
Time	Description